HYDROCARBON SOURCE POTENTIAL AND ORGANIC GEOCHEMICAL NATURE OF SOURCE ROCKS AND CRUDE OILS IN THE ILLINOIS BASIN

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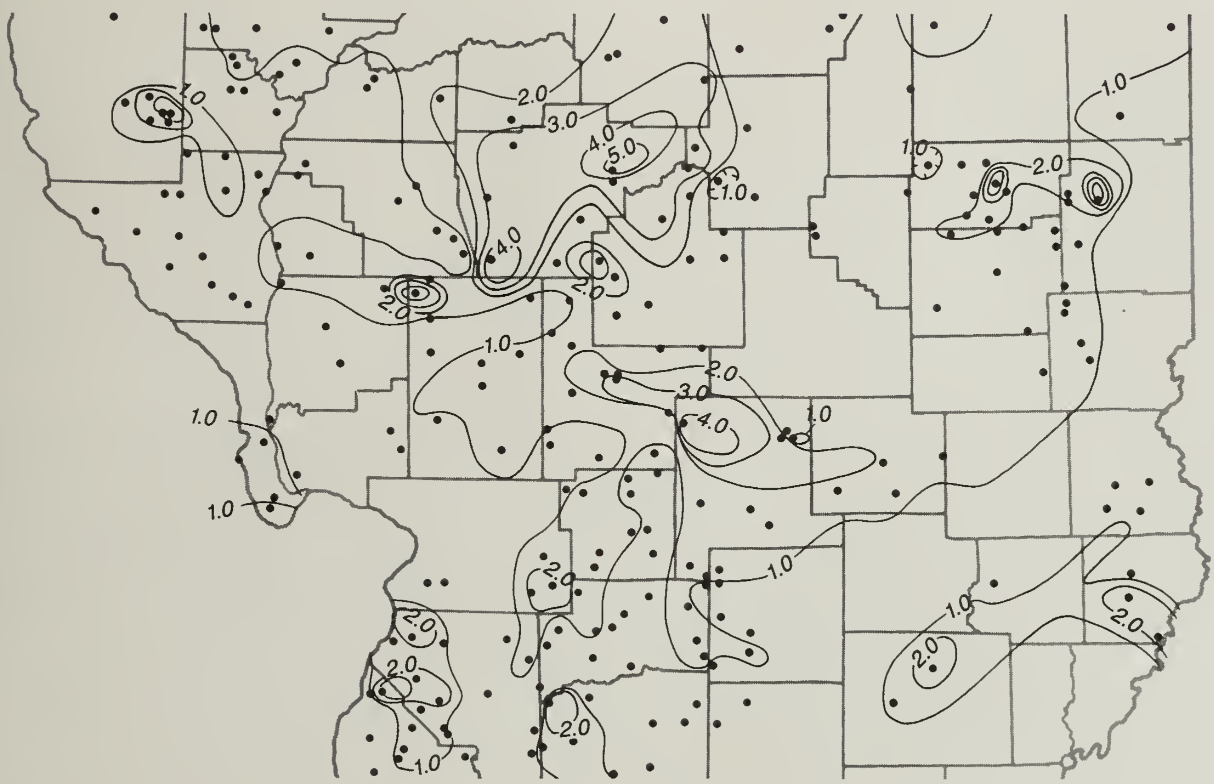

ILLINOIS PETROLEUM 136 1991

Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY

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ABSTRACT

Total organic carbon data were compiled for 936 samples from four shales in the Illinois Basin; 850 samples have total organic carbon contents great enough to be considered potential petroleum source rock (>0.5%).

A total of 159 core samples of the New Albany Group from throughout the Illinois Basin were evaluated for their petroleum potential. More limited areas were sampled for Ordovician (30 samples) and Pennsylvanian (17 samples) source rocks. Rock-Eval analyses indicate that the Pennsylvanian Carbondale Formation (Anna and Energy Shale Members) is immature with respect to hydrocarbon generation. The rocks of the Devonian-Mississippian New Albany Group from eastern and southeastern Illinois, presently buried at about 3,000 to 5,000 feet (900 to 1,500 m), contain abundant, marginally mature type II kerogen—an indication of a petroleum potential within the oil-generation window. Shales of the Middle Ordovician Guttenberg Formation from north and northwestern Illinois have good petroleum potential. The oil-source potential for the shales of the Upper Ordovician Maquoketa Group from southeastern Illinois is rather limited, although they have not been adequately sampled.

The chemical characteristics of 83 crude oils from the Illinois Basin were examined by gas chromatography. Crude oils of younger reservoirs (Pennsylvanian, Mississippian) and most Devonian and Silurian oils contain aliphatic hydrocarbons similar to those of solvent extracts from the New Albany from the southeastern part of Illinois. The gas chromatographic fingerprints of the Ordovician Trenton/Galena oils are distinctly different from those of the crude oils from younger reservoirs. Their pattern more closely resembles that of the Guttenberg Formation than the Maquoketa Group. This study suggests that Illinois Basin crude oils can be classified as having at least two distinct sources, one probably originating from Ordovician rocks and the other originating from sources younger than Ordovician age, probably the New Albany Group.

INTRODUCTION

Pyrolysis analysis, petrographic (visual) assessment, and organic geochemical characterization play important roles in source-rock evaluation and hydrocarbon exploration. Thick, organic-rich, black shales occur within the New Albany Group of the Illinois Basin (Reinbold 1978, Basset and Hasenmueller 1978, Schwalb and Potter 1978). Other organic-rich rocks, such as the Ordovician Maquoketa Group, have also been noted in the basin (Lumm and Nelson 1985, J. E. Crockett, personal communication, 1987). However, except for analyses of total organic carbon (TOC) content and petrographic assessment of some Illinois Basin shales (Stevenson 1971, Stevenson and Dickerson 1971, Barrows and Cluff 1984, Frost et al. 1985, Barrows 1985), only limited organic-geochemical data have been reported (Stevenson and Dickerson 1969, Chou and Dickerson 1979, Chou and Dickerson 1985, Chou et al. 1986, Hatch et al. 1987, Longman and Palmer 1987, Chou et al. 1988).

Hydrocarbon source-rock potential is a function of the quantity (TOC), kerogen type, and thermal maturity of the organic matter in shale. This report contains TOC percentages for 936 shale samples from the Illinois Basin region. The source rock potentials of shales in the Ordovician Guttenberg Formation and Maquoketa Group, the Devonian-Mississippian New Albany Group, and the Pennsylvanian Carbondale Formation (Anna and Energy Shale Members) were analyzed using pyrolysis (Rock-Eval) and gas chromatographic techniques. The New Albany Group from wide areas of the Illinois Basin was evaluated; whereas the Ordovician and Pennsylvanian rocks from more limited areas were evaluated. Eighty-three crude oils from Pennsylvanian, Mississippian, Devonian, Silurian, and Ordovician reservoirs in the Illinois Basin also were chemically characterized by gas chromatography.

Table 1 Total organic carbon (TOC) weight percentages for shales from the Guttenberg Formation

Sample	Location Sec, T-R	Depth (ft)	TOC (%)
Gutt-1	22, 28N-9E*	outcrop	45.10
Gutt-2	20, 76N-9W†	952.0	28.70
Gutt-3	13, 4N-9W‡	906.5	12.79
Gutt-4	13, 4N-9W‡	907.3	15.35
Gutt-5	13, 4N-9W‡	909.9	15.90
Gutt-6	7, 28N-6E*	260.0	38.88
Gutt-7	7, 28N-6E*	260.5	50.80
Gutt-8	7, 28N-6E*	261.0	13.90
Gutt-9	7, 28N-6E*	262.2	26.20
Gutt-10	7, 28N-6E*	262.5	31.30
Gutt-11	7, 28N-6E*	262.8	30.70

* Stephenson County, Illinois
† Washington County, Iowa
‡ Hancock County, Illinois

SOURCE ROCKS

Total Organic Carbon Content

Percentages of TOC were compiled for shales from four stratigraphic intervals in the Illinois Basin. Data for 936 samples are tabulated in this study. Of these, 874 samples were previously analyzed (Stevenson and Dickerson 1971, Frost et al. 1985, Shaffer et al. 1978, Robl et al. 1983, Barrows 1985), and 62 samples were analyzed for this study. The sources of these 62 samples are reviewed below.

Guttenberg Formation (Ordovician) Samples of the Guttenberg Formation from one outcrop and two drill holes in Stephenson and Hancock Counties, Illinois, and a drill hole in Washington County, Iowa, were analyzed. Table 1 lists the location, depth, and TOC data of the 11 samples. The results indicate that the Ordovician Guttenberg Formation from northwestern Illinois and adjacent southeastern Iowa has remarkably high TOC values, ranging from 12.79 to 50.80 percent.

Maquoketa Group (Ordovician) Nineteen samples of the Maquoketa Group collected from two drill holes in White and Clinton Counties, Illinois, were analyzed (table 2). Data on TOC from 341 shale samples of the Maquoketa Group, including 317 obtained by Stevenson and Dickerson (1971, appendix A) and 5 obtained by Barrows (1985) (appendix B), also were compiled and examined. The TOC values for all 341 samples from the Maquoketa Group range from 0.10 to 7.26 percent. For reference points on the occurrence and level of richness of the source rocks, a contour map (fig. 1) was constructed: Stevenson and Dickerson's data are for single analyses of composited samples for the interval indicated in appendix A; data in this study are average values of multiple samples indicated in table 2; Barrows' data are for single samples at depths shown in appendix B. Values for TOC greater than 3 percent occur in the following five regions: (1) western Illinois (Adams and Fulton Counties), (2) south-central Illinois (Macoupin, Sangamon, Christian, and Macon Counties), (3) central Illinois (Montgomery, and Fayette Counties), (4) eastern Illinois (Douglas and Edgar Counties), and (5) southwestern Illinois (Monroe and St. Clair Counties). Because of the limitations in the areal and stratigraphic distribution of samples and in facies control within the Maquoketa Group, the exact cause of this variation is not yet fully understood and needs further investigation.

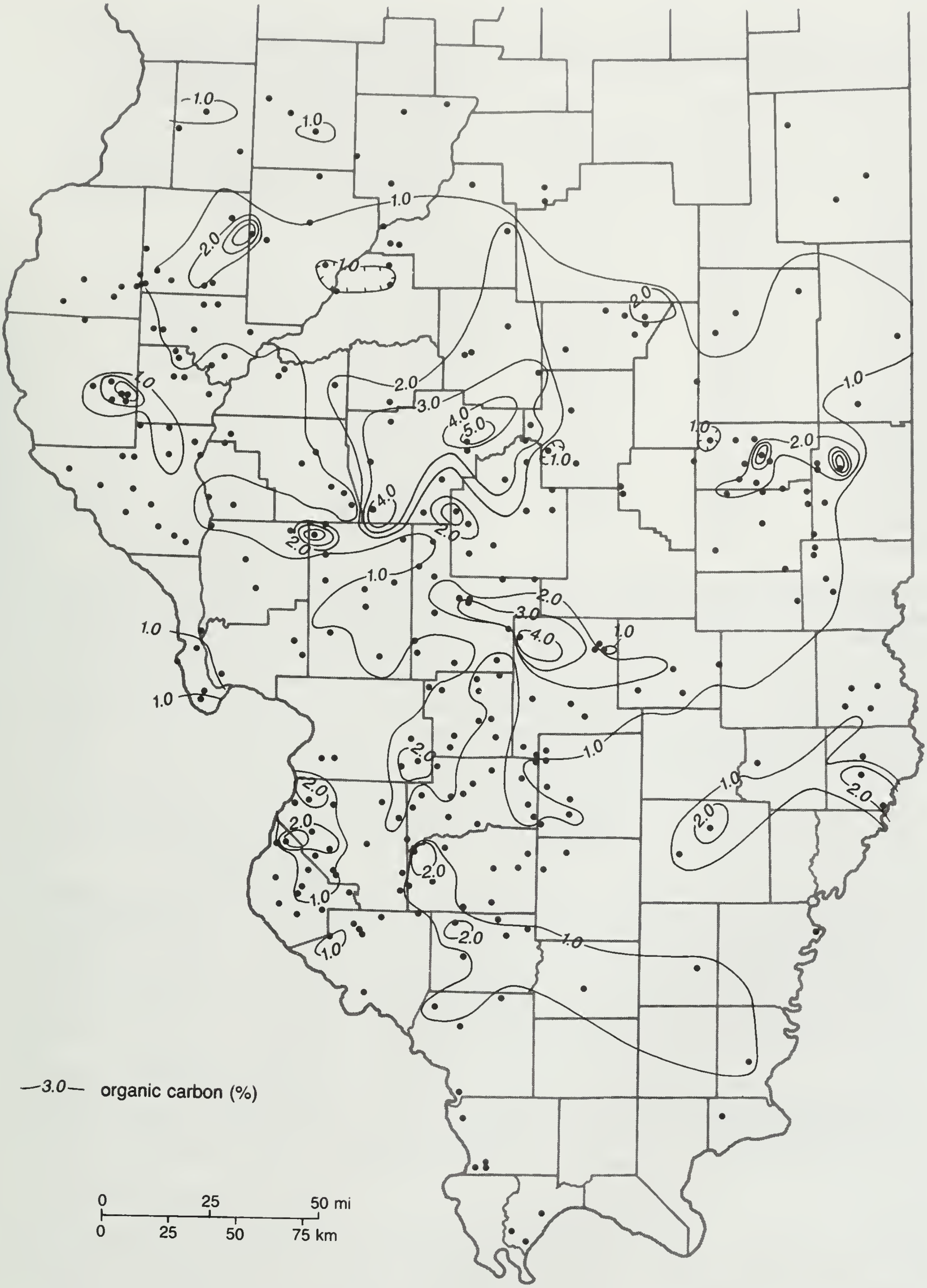


Figure 1 Variation in the geographic distribution of organic carbon content of shales from the Maquoketa Group.

Table 2 Total organic carbon (TOC) weight percentages showing vertical variation for shales from the Maquoketa Group

Sample	Depth (ft)	TOC (%)
Drill hole at Sec. 27, T4S-R14W (White Co., Illinois)		
Maquo-1	6,092.0	0.30
Maquo-2	6,112.0	0.10
Maquo-3	6,132.0	0.20
Maquo-4	6,152.0	0.10
Maquo-5	6,172.0	0.10
Maquo-6	6,192.0	0.60
Maquo-7	6,212.0	0.60
Maquo-8	6,232.0	0.80
Maquo-9	6,252.0	0.40
Maquo-10	6,270.0	0.40
Maquo-11	6,272.0	1.10
Maquo-12	6,290.0	0.60
Maquo-13	6,292.0	0.30
Maquo-14	6,312.0	0.60
Maquo-15	6,332.0	1.70
Maquo-16	6,412.0	0.40
Maquo-17	6,417.0	0.20
Drill hole at Sec. 3, T2N-R3W (Clinton Co., Illinois)		
Maquo-18	3,427.2	0.50
Maquo-19	3,434.5	0.60

New Albany Group (Devonian-Mississippian) Samples from the New Albany Group (Devonian-Mississippian) have been extensively studied because this stratigraphic unit contains the thickest and most widespread beds of black shale in the Illinois Basin and is a major source for oil and gas accumulations (Barrows and Cluff 1984).

Lineback (1968, 1980) subdivided the New Albany Shale into the following members, in ascending order: the Blocher, Sweetland Creek-Selmier, Grassy Creek, and Hannibal-Saverton Shale Members (fig. 2). In Illinois, these subdivisions are classified as formations and the New Albany is classified as a group. The data of Frost et al. (1985) indicate that the lowest organic carbon values (<2%) were generally found in the uppermost shale units, the Hannibal-Saverton Shales. Medial TOC values (between 2% and 5%) were found in both the Grassy Creek and Sweetland Creek Shales in the northwestern part of the basin. In all other parts of the basin, the Grassy Creek and Sweetland Creek-Selmier Shales had high to very high TOC values, ranging from 5 to 9 percent. The lowermost shale unit, the Blocher Shale, also had high TOC values, ranging from 4 to 9 percent.

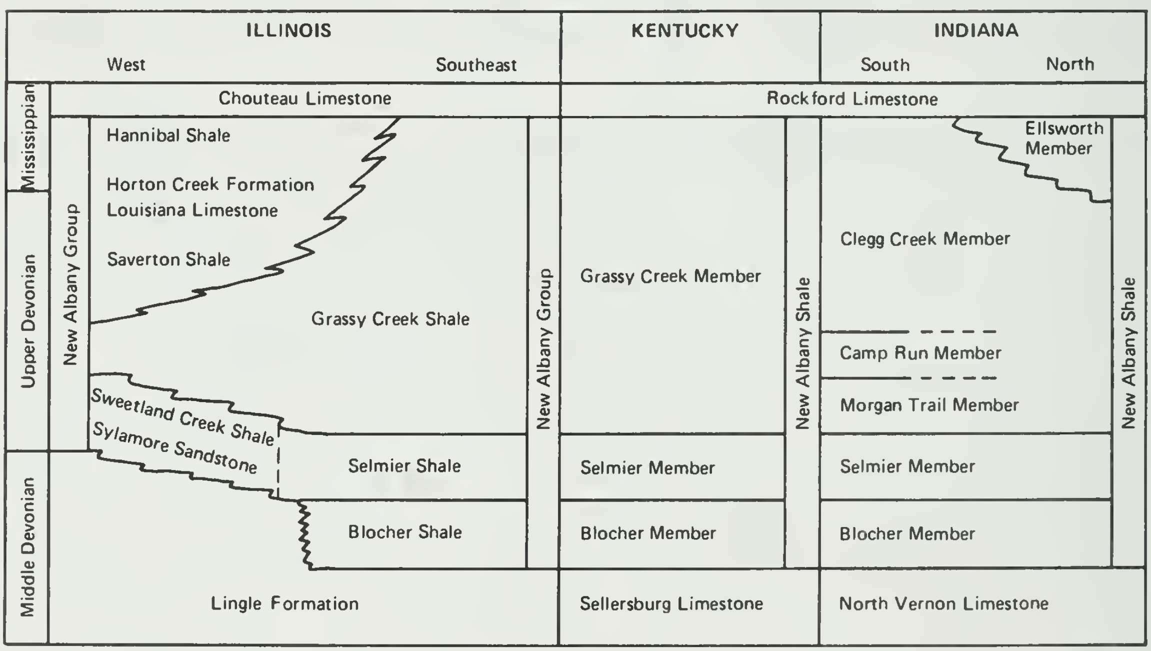


Figure 2 Stratigraphic nomenclature of the New Albany Group in the Illinois Basin (after Lineback 1980).

Table 3 Total organic carbon (TOC) weight percentages for the Anna and Energy Shale Members of Pennsylvanian Carbondale Formation

	Location		
Sample	County	Coal mine (mine no.)	TOC (%)
Anna-1	Perry	Captain (873)	13.40
Anna-2	Montgomery	Hillsboro (871)	31.20
Anna-3	Franklin	Old Ben No.24 (866)	26.40
Anna-4	Macoupin	Crown II (933)	32.00
Anna-5	Franklin	Old Ben No. 24 (866)	2.90
Anna-6	Franklin	Old Ben No. 24 (866)	8.40
Anna-7	Franklin	Old Ben No. 24 (866)	9.60
Anna-8	Franklin	Old Ben No. 24 (866)	12.00
Anna-9	Franklin	Old Ben No. 24 (866)	2.70
Anna-10	Franklin	Old Ben No. 26 (879)	19.10
Energy-1	Jefferson	Inland No.1 (877)	1.80
Energy-2	Peoria	Elm (887)	5.20
Energy-3	Perry	Captain (873)	5.10
Energy-4	Franklin	Old Ben No.24 (866)	0.80
Energy-5	Jefferson	Orient No.6 (885)	6.00
Energy-6	Franklin	Old Ben No. 24 (866)	4.30
Energy-7	Franklin	Old Ben No. 26 (879)	1.70

Locations and sample numbers for the Grassy Creek Shale and Sweetland Creek-Selmier Shale samples in Illinois are shown in figure 3. Geographic variations of the TOC values of the samples are depicted by the contour map shown in figure 4. Because of the limited availability of data from Indiana and Kentucky, contouring was done only for Illinois. Datum points used for map construction are average values for multiple samples analyzed by Frost et al. (1985).

Analyses for TOC of the New Albany Shale in Indiana have been reported by Shaffer et al. (1978). Their analyses and the limited number of analyses by Robl et al. (1983) and Frost et al. (1985) of samples from Indiana and Kentucky indicate that the TOC values in these areas are comparable to those obtained for Illinois shales. Indiana samples with higher TOC values have regional averages ranging from 3 to 9 percent, whereas samples with lower TOC values range from 1 to 2 percent.

Anna and Energy Shale Members, Carbondale Formation (Pennsylvanian) Seventeen samples of the Anna and Energy Shale collected from the roofs of coal mines in Montgomery, Macoupin, Jefferson, and Franklin Counties, Illinois, were analyzed. Table 3 lists the stratigraphic units, locations, and TOC data for the samples. The marine-deposited Anna Shale has a relatively high TOC content that ranges from 2.70 to 32.00 percent, whereas the nonmarine Energy Shale has a moderate TOC content that ranges from 0.80 to 6.00 percent (table 3).

Table 4 summarizes the range and distribution of the TOC content of shales from the four stratigraphic intervals examined. The TOC content of 91 percent of the shales analyzed, 850 of the 936 samples, was greater than the 0.5 percent critical lower limit for potential petroleum source rocks that was cited by Tissot and Welte (1984).

Pyrolysis (Rock-Eval) Analysis

Pyrolysis analysis by Rock-Eval was performed, following the methods of Espitalie et al. (1977), on 206 shale samples. Core samples of the New Albany Group from throughout the Illinois Basin were evaluated, whereas more limited areas were sampled for Ordovician and Pennsylvanian source rocks. The results for each unit are discussed below.

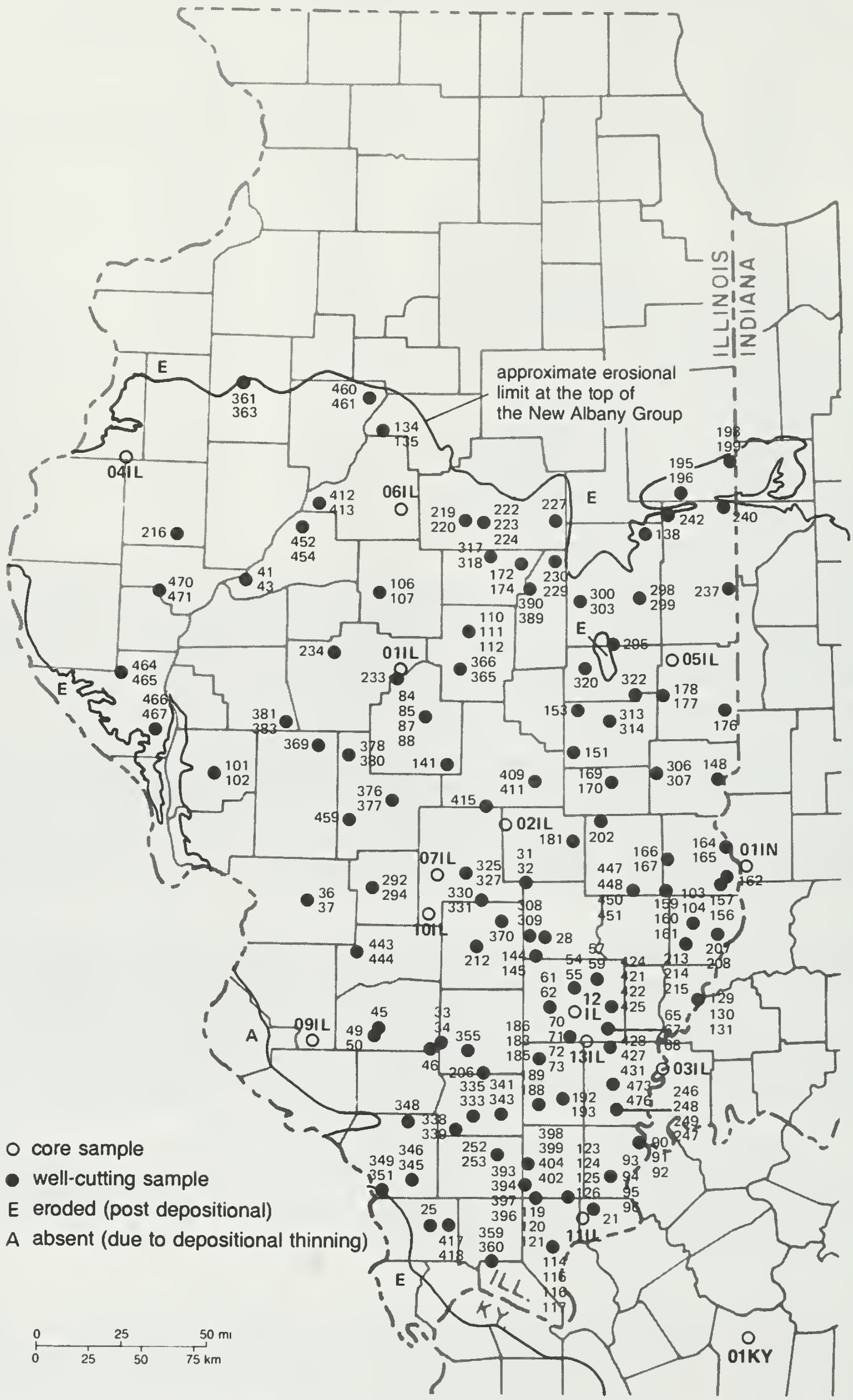


Figure 3 Locations of New Albany Group cores and well-cutting samples used for chemical analyses.

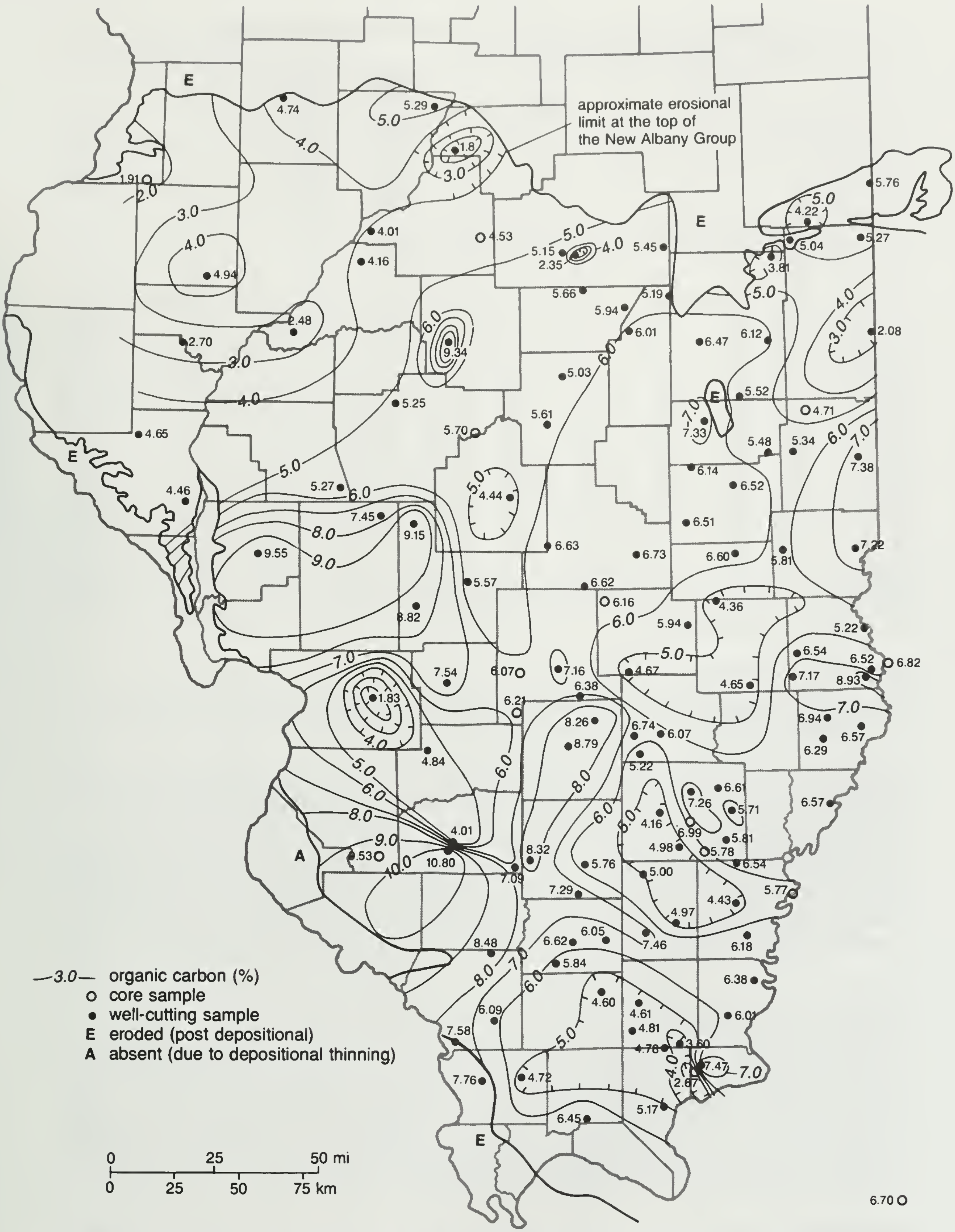


Figure 4 Variation in the geographic distribution of organic carbon content of the Grassy Creek Shale and the Sweetland Creek-Selmier Shales.

Table 4 Range and distribution of the total organic carbon (TOC) content for shales from four stratigraphic units in the Illinois Basin

Shale	Total no. samples	TOC <0.5%	TOC 0.5–1%	TOC >1%	Highest TOC	Lowest TOC
Anna and Energy	17	0	1	16	32.00	0.80
New Albany	567*	49	48	470	19.70	0.01
Maquoketa	341†	37	143	161	7.26	0.10
Guttenberg	11	0	0	11	50.80	12.79

* Frost et al. 1985, Shaffer et al. 1978, Robl et al. 1983.
† Stevenson and Dickerson 1971, Barrows 1985, M. Chou, this paper.

Table 5 Pyrolysis analysis data for the Guttenberg Formation (parameters are defined in appendix C)*

Sample	Qty g	T_{max} °C	S_1	S_2	S_3	S_2/S_3	PC	TOC %	HI	OI	S_1+S_2 kg/t
Gutt-1	10.5	433	6.47	279.61	21.33	13.10	23.84	45.10	619	47	286.08
Gutt-2	15.3	448	5.35	276.60	3.55	77.04	23.62	28.70	963	12	281.95
Gutt-3	60.7	435	1.61	95.42	1.15	82.97	8.08	12.79	746	9	97.03
Gutt-4	52.4	439	1.56	118.93	1.41	84.34	10.04	15.35	774	34	120.59
Gutt-5	53.3	442	1.93	114.14	1.35	84.54	0.67	15.90	718	8	116.07
Gutt-6	8.1	448	3.08	337.77	2.96	114.11	28.40	38.88	870	7	340.85
Gutt-7	6.3	449	4.12	435.55	3.17	137.39	36.63	50.80	857	6	439.67
Gutt-8	59.4	445	1.49	98.04	0.70	140.05	8.29	13.90	705	5	99.53
Gutt-9	23.6	441	3.09	204.40	1.48	138.10	17.29	26.20	780	5	207.49
Gutt-10	12.7	445	3.07	264.56	1.88	140.72	22.30	31.30	845	6	267.63
Gutt-11	16.7	446	2.63	240.95	1.97	122.30	20.29	30.70	784	6	243.58

* For sample locations, see table 1.

Ordovician

Pyrolysis analysis data for the 11 Guttenberg Formation samples analyzed in this study are listed in table 5, and for the 19 Maquoketa Group samples, in table 6.

Figure 5 shows the hydrogen index relative to the oxygen index for kerogen-type identification (modified van Krevelen diagram; Tissot and Welte 1984) for the Ordovician samples. The Maquoketa samples generally do not appear to be representative of Maquoketa rocks elsewhere in the Illinois Basin. The TOC values are low, and low values such as these are known to produce results that are suspect in Rock-Eval analysis. Nevertheless, the current analyses for these Maquoketa samples show that they are depleted in hydrogen and their index values mostly plot near the gas-prone type III kerogen path. In contrast, the Guttenberg samples have a higher hydrogen content and plot near the oil-prone type I and II kerogen paths.

Definitions for both T_{max} and generative potential (S_1+S_2) are given in appendix C. The T_{max} values for the Maquoketa Group, which range from 418 to 447°C (table 6) are generally not reliable because of the low TOCs. The T_{max} values for the Guttenberg Formation, which range from 433 to 448°C (table 5), indicate moderate levels of thermal maturity for this shale unit. However, the generative potentials (S_1+S_2) for the Maquoketa samples range from 0.10 to 3.04 kg of hydrocarbon per ton of rock (kg/t), whereas the generative potentials for the Guttenberg samples range from 97.03 to 439.67 kg/t. These data suggest that the Guttenberg Formation in the area sampled has excellent potential as a source rock for oil and that the Maquoketa in White and Clinton County wells has only limited potential as an oil-source rock.

New Albany

Samples taken from cores of the New Albany Group from western (04IL), west-central (06IL), central (02IL), southeastern (03IL, 12IL, 13IL), and southern Illinois (11IL), western Indiana

Table 6 Pyrolysis analysis and total organic carbon data for the Maquoketa Group (parameters are defined in appendix C)*

Sample	Qty g	T_{max} °C	S_1	S_2	S_3	S_2/S_3	PC	TOC %	HI	OI	S_1+S_2 kg/t
Maquo-1	104.8	428	0.09	0.18	0.41	0.43	0.02	0.30	60	136	0.27
Maquo-2	108.3	447	0.04	0.10	0.24	0.41	0.01	0.10	100	240	0.14
Maquo-3	100.8	418	0.06	0.08	0.34	0.23	0.01	0.20	40	170	0.14
Maquo-4	102.4	420	0.04	0.06	0.28	0.21	0.00	0.10	60	280	0.12
Maquo-5	101.3	424	0.04	0.08	0.20	0.40	0.01	0.10	80	200	0.10
Maquo-6	101.7	438	0.39	0.98	0.30	3.26	0.11	0.60	163	50	1.37
Maquo-7	100.6	438	0.45	0.92	0.29	3.17	0.11	0.60	153	48	1.37
Maquo-8	104.3	429	1.21	1.81	0.52	3.48	0.25	0.80	226	65	3.02
Maquo-9	106.0	437	0.22	0.56	0.76	0.73	0.06	0.40	140	190	0.78
Maquo-10	102.0	435	0.42	0.50	0.43	1.16	0.07	0.40	125	107	0.92
Maquo-11	102.8	441	0.97	2.07	1.18	1.75	0.25	1.10	188	107	3.04
Maquo-12	101.8	440	0.51	0.97	1.25	0.77	0.12	0.60	161	208	1.48
Maquo-13	107.9	439	0.19	0.30	0.54	0.55	0.04	0.30	100	180	0.49
Maquo-14	102.9	438	0.46	0.81	0.69	1.17	0.10	0.60	135	115	1.27
Maquo-15	101.8	441	0.65	1.27	0.82	1.54	0.16	1.70	74	48	1.92
Maquo-16	101.1	437	0.14	0.33	1.10	0.30	0.03	0.40	82	275	0.47
Maquo-17	101.1	436	0.06	0.14	0.21	0.66	0.01	0.20	70	105	0.20
Maquo-18	107.0	433	0.09	1.01	0.68	1.48	0.09	0.50	202	136	1.10
Maquo-19	102.9	434	0.12	1.47	0.74	1.98	0.13	0.60	245	123	1.59

* For sample locations, see table 2.

(01IN), and western Kentucky (01KY) were analyzed by pyrolysis. Drill-hole locations are shown in figure 3. The analytical results are listed in appendix D.

When plotted on modified van Krevelen diagrams, the values cluster into distinctive groups according to the regions from which the samples were collected. Except for samples from Kentucky (01KY), samples from the drill holes in western (04IL) and west-central (06IL) Illinois (fig. 6a) exhibited higher hydrogen indices and lower oxygen indices than the other samples. Those from southwestern Indiana (01IN), and southeastern Illinois (12IL, 13IL, 03IL) generally plotted along the oil-prone type II kerogen path (fig. 6b). Those from the Hicks Dome area in southern Illinois (fig. 6c, 11IL) were very depleted in hydrogen (lower hydrogen indices) and distributed along the gas-prone type III kerogen evolution path. New Albany Group shales from western and west-central Illinois are classified as borderline immature source rocks because most have T_{max} values close to but generally less than 435°C (appendix D). The average value of T_{max} for the 04IL core is 433°C and for 06IL core is 434°C (table 7). The samples have relatively low mean generative potentials, 3.7 kg/t for 04IL and 9.3 kg/t for 06IL cores; most samples from the 04IL and 06IL cores are of the Hannibal-Saverton (appendix D), the uppermost shale units of the New Albany Group, which are low in TOC.

Most of the shales from central, eastern, and southeastern Illinois and western Kentucky have moderate maturity in the oil-generation zone. The average T_{max} values for these cores range from 437° to 443°C and the average values of generative potentials from 18.6 to 33.4 kg/t. The higher level of thermal maturity and generative potentials for these cores indicate that the New Albany Group shales have good potential as oil-source rocks. Shales from the Hicks Dome area in southern Illinois are thermally mature and in the gas-generation zone. The T_{max} values range from 434° to 461°C (appendix D) with an average of 452°C (table 7) and the average generative potential of these shales, 1.9 kg/t, is low. The high thermal maturity of these shales is probably the consequence of locally high heat flow accompanying igneous activity in this area. Similar regional variations in thermal maturity for the New Albany Group, determined on the basis of fluorescence and vitrinite reflectance, were reported by Barrows and Cluff (1984).

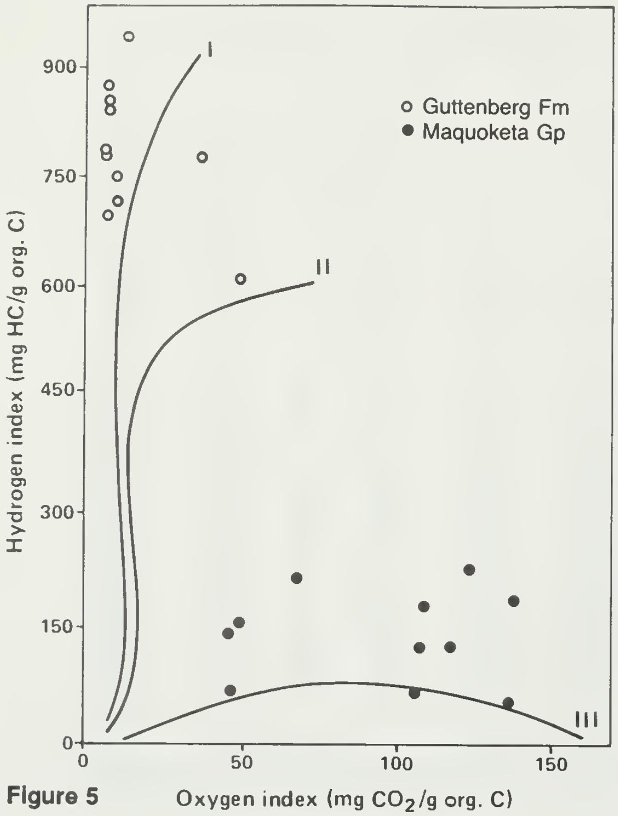


Figure 5

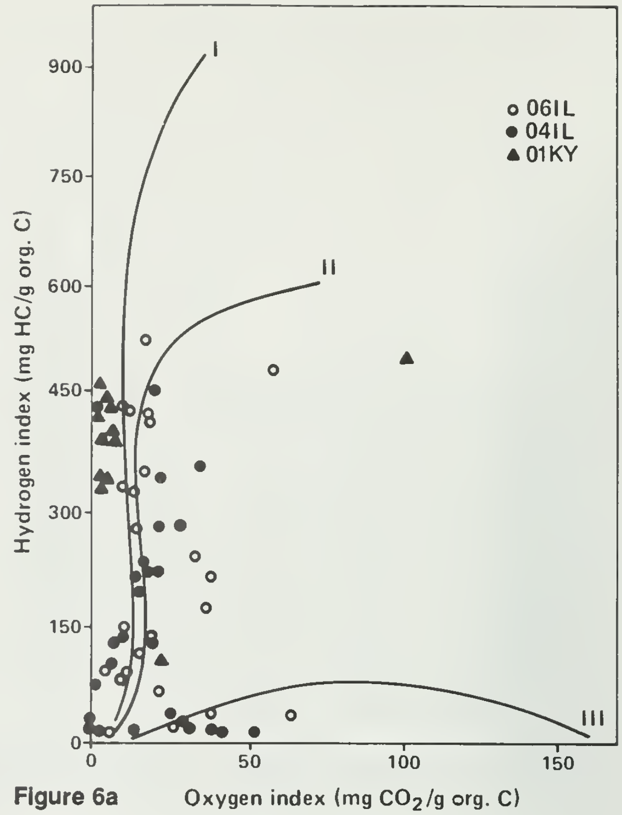


Figure 6a

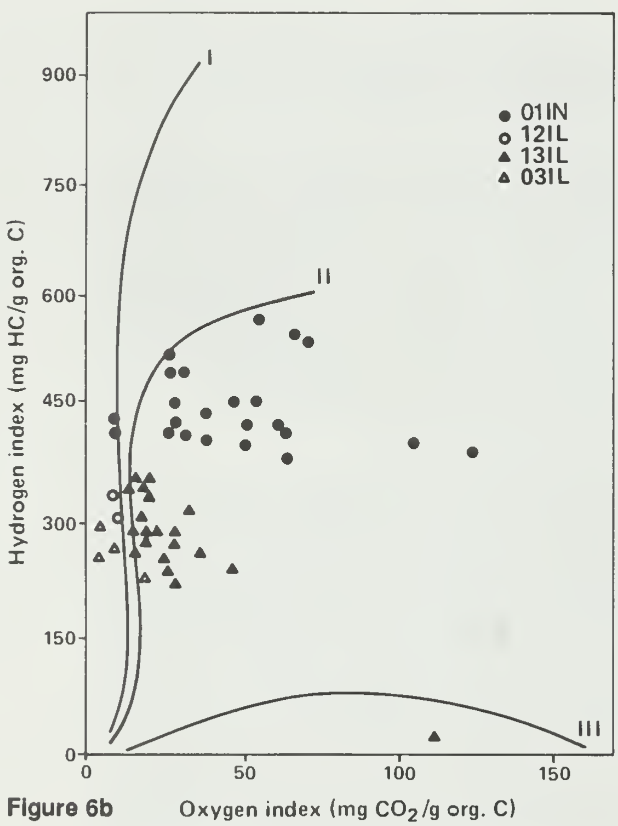


Figure 6b

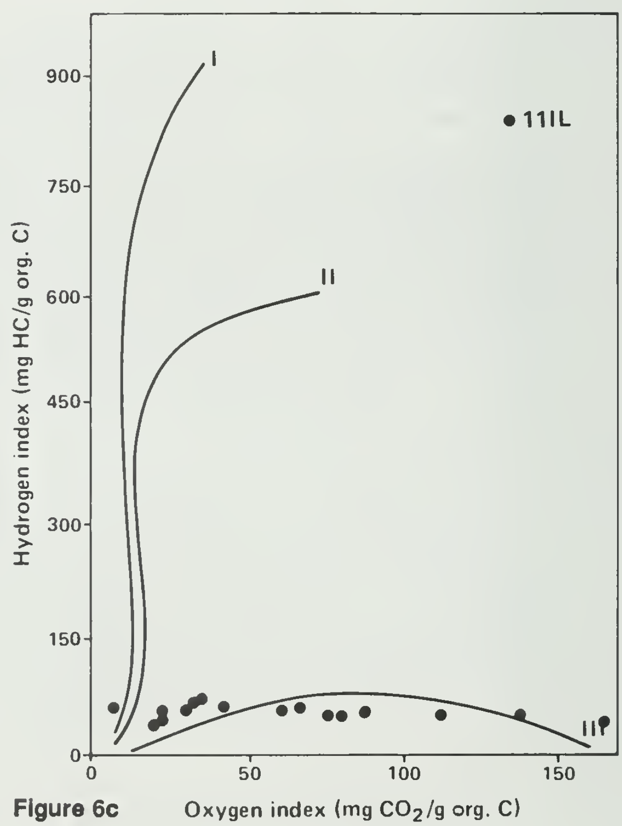


Figure 6c

Table 7 Pyrolysis analysis data for cores from western and west-central (04IL and 06IL), central (02IL), eastern and southeastern (12IL, 13IL, and 03IL), and southern (11IL) Illinois and adjacent western Indiana (01IN) and western Kentucky (01KY)*

Maturity	Core	TOC %	T_{max} °C	S_1+S_2 kg/t	No. samples analyzed
Immature	04IL	1.50	433	3.7	27
	06IL	2.51	434	9.3	28
Mature (oil zone)	02IL	5.10	438	21.5	10
	01IN	6.50	437	33.4	25
	12IL	6.39	443	20.1	2
	13IL	5.26	440	18.6	23
	03IL	6.34	443	20.5	6
	01KY	5.77	443	25.5	16
Overmature (gas zone)	11IL	2.62	452	1.9	22

* Data listed are average values for samples from each core.

Table 8 Pyrolysis analysis data for the Anna and Energy Shale Members of Pennsylvanian Carbondale Formation (parameters are defined in appendix C; sample locations appear on table 3)

Sample	T_{max} °C	S_1	S_2	S_3	PI	S_2/S_3	PC	TOC %	HI	OI	S_1+S_2 kg/t
Anna-1	417	1.58	39.00	2.25	0.04	17.33	3.38	13.40	297	17	40.58
Anna-2	413	6.98	95.75	8.13	0.07	11.77	8.56	31.20	306	26	102.73
Anna-3	421	4.65	75.24	5.21	0.06	14.44	6.65	26.40	286	19	79.89
Anna-4	416	5.16	88.48	8.38	0.06	10.55	7.80	32.00	276	26	93.64
Anna-5	433	1.36	3.32	2.15	0.29	1.54	0.39	2.90	114	74	4.68
Anna-6	417	2.10	15.22	3.43	0.12	4.43	1.44	8.40	181	40	17.32
Anna-7	421	0.28	1.82	4.40	0.13	0.41	0.17	9.60	18	45	2.10
Anna-8	430	0.84	2.71	5.02	0.24	0.53	0.29	12.00	22	41	3.55
Anna-9	429	0.84	2.84	5.17	0.23	0.54	0.30	2.70	105	191	3.68
Anna-10	424	3.93	61.05	7.64	0.06	7.99	5.41	19.10	319	40	64.98
Energy-1	432	0.33	1.51	0.27	0.18	5.75	0.15	1.80	84	15	1.84
Energy-2	430	0.26	4.73	5.35	0.05	0.88	0.41	5.20	90	102	4.99
Energy-3	419	0.17	3.90	2.84	0.04	1.37	0.33	5.10	76	55	4.07
Energy-4	409	0.63	0.29	2.60	0.68	0.11	0.07	0.80	36	325	0.92
Energy-5	426	0.77	7.53	2.73	0.09	2.75	0.69	6.00	125	45	8.30
Energy-6	407	0.29	4.31	2.78	0.06	1.55	0.38	4.30	100	64	4.60
Energy-7	435	0.37	1.40	6.25	0.21	0.22	0.14	1.70	82	367	1.77

Pennsylvanian

Pyrolysis analysis data for the Pennsylvanian Anna and Energy Shale Members of the Carbondale Formation are listed in table 8. Plots of ratios for the Anna and Energy Shales on a modified van Krevelen diagram indicate that they are distributed between type II and type III kerogen paths (fig. 7). The Energy Shale is more gas prone and depleted in hydrogen (lower

Figures 5 and 6 *(page 10)*

Hydrogen index relative to oxygen index (modified van Krevelen diagram) for

5 samples from the Ordovician Maquoketa Group and Guttenberg Formation. Eight samples of the Maquoketa Group were not plotted because their oxygen indices are greater than 170.

6 New Albany Group samples from *(a)* western and west-central Illinois (04IL, 06IL) and western Kentucky (01KY); *(b)* eastern Indiana (01IN), southeastern Illinois (12IL, 13IL, 03IL); and *(c)* southern Illinois (11IL).

hydrogen index) than the Anna Shale and plots mainly along the type III or "woody" kerogen path. Values for T_{max} (table 8) from Rock-Eval pyrolysis for the Anna and Energy Shales range from 407°C (immature) to 435°C (barely mature). The average hydrocarbon-generative potential for the Anna Shale (41.3 kg/t) is much higher than that for the Energy Shale (3.8 kg/t).

Overall, the results of pyrolysis analysis indicate an excellent oil-source potential for the Guttenberg Formation, limited oil-source potential for the Maquoketa Group, oil and gas potential for the New Albany Group, and immaturity for the Anna and Energy Shales. The New Albany in western and west-central Illinois is an immature potential source, but is a mature source of oil in the deeper part of the Illinois Basin, southeastern Illinois, and adjacent parts of western Indiana and western Kentucky. In extreme southern Illinois (Hicks Dome area), the New Albany is overmature but has some potential for gas generation.

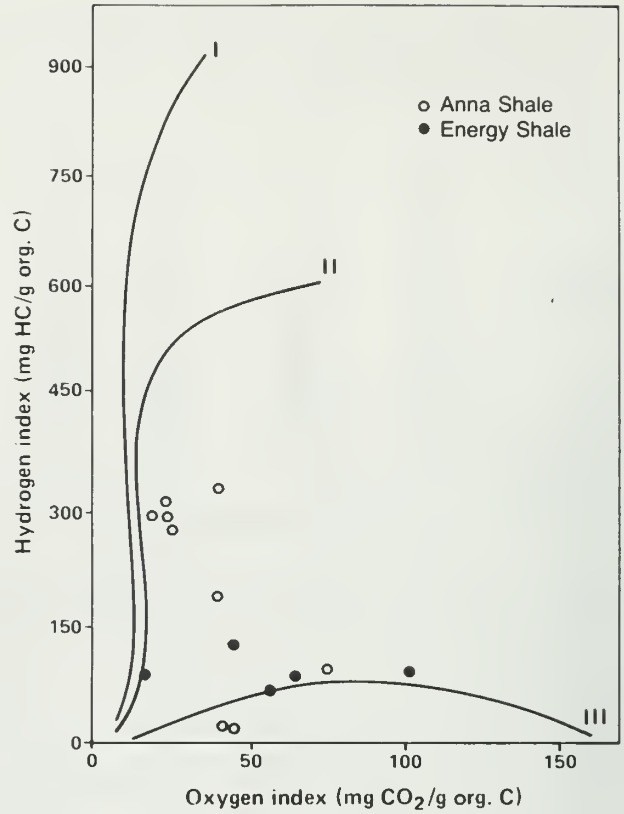


Figure 7 Hydrogen index relative to oxygen index (modified van Krevelen diagram) for Anna Shale and Energy Shale Members of the Pennsylvanian Carbondale Formation. One Anna Shale and two Energy Shale samples were not plotted; their oxygen indices are greater than 150.

CRUDE OILS

Oil Samples

Gas chromatography (GC)/flame ionization detection was used to analyze 83 samples of crude oils (table 9): 5 from Pennsylvanian, 16 from Mississippian-Chesterian, 26 from Mississippian-Valmeyeran, 8 from Devonian, 17 from Silurian, and 11 from Ordovician reservoirs.

Pennsylvanian and Mississippian

Figure 8 shows typical GC fingerprints for crude oils from (a) Pennsylvanian, (b) Mississippian-Chesterian, and (c) Mississippian-Valmeyeran reservoirs. Each pattern shows moderate contents of pristane and phytane, and the content of *n*-alkanes progressively decreases with increasing carbon number.

Devonian

Crude oils from Devonian reservoirs have either of two different GC fingerprint patterns. The first pattern (fig. 8d), for oils from Christian, Clinton, Hamilton, and Washington Counties, Illinois, is similar to the pattern of the Pennsylvanian and Mississippian oils. In contrast, the pattern (fig. 8e) for the Devonian oil from Piatt County, Illinois, contains *n*-alkanes distributed around two median molecular weights—one centered around n-C_5 and the other around n-C_{18}. In the lower-molecular-weight area, mainly light hydrocarbons (n-C_{11-}) are present; whereas in the higher-molecular-weight area, a broader spectrum of *n*-alkanes is observed. Also, the concentrations of pristane and phytane are higher than those in any of the other oils.

Table 9 Sample identification and locations of crude oils

Sample	County	Location	Field*
Pennsylvanian			
57-Penn-1	Crawford	Sec. 32 T7N R13W	Main C.
55-Penn-3	Lawrence	Sec. 32 T4N R12W	Lawrence
36-Penn-1	Edwards	Sec. 11 T3S R10E	Albion C.
50-Penn-1	Bond	Sec. 22 T5N R4W	Old Ripley
49-Penn-1	Madison	Sec. 20 T6N R6W	Livingston
Mississippian-Chesterian			
43-Ben-1	Marion	Sec. 31 T2N R2E	Salem
50-C-1	Bond	Sec. 21 T6N R2W	Woburn C.
ISGS-150	Fayette	Sec. 22 T5N R4E	Laclede
025-C-1	Clay (SW SE NW)	Sec. 34 T3N R8E	Clay City C.
20-Walt-1	Gallatin	Sec. 24 T7S R9E	Hearld C.
025-C-2	Clay (SW SW NW)	Sec. 34 T3N R8E	Clay City C.
ISGS-145	Franklin	Sec. 4 T6S R3E	Whittington South
32-Ben-1	Washington	Sec. 29 T3S R4W	McKinley
41-Ben-1	Clay	Sec. 6 T2N R8E	Clay City C.
22-C-1	White	Sec. 13 T6S R8E	Roland C.
ISGS-139	Clinton	Sec. 13 T1N R4W	Bartelso
20-Walt-2	White	Sec. 13 T7S R9E	Hearld C.
53-C-1	Clay	Sec. 5 T5N R7E	Sailor Springs C.
ISGS-140	Washington	Sec. 28 T21S R1W	Irvington
60-Beth-1	Fayette	Sec. 22 T5N R4E	Laclede
25-C-1	Perry	Sec. 25 T4S R2W	Tamaroa W.
Mississippian-Valmeyeran			
96-Son-1	De Witt	Sec. 34 T21N R4E	Parnell
41-SG-1	Clay	Sec. 5 T2N R8E	Clay City C.
73-Carp-1	Clark	Sec. 25 T10N R14W	Martinsville
ISGS-127	Jefferson	Sec. 8 T3S R4E	Markham City West
ISGS-143	Franklin	Sec. 20 T6S R2E	Buckner
22-AV-1	White	Sec. 14 T5S R8E	Trumball C.
ISGS-144	Franklin	Sec. 18 T6S R2E	Buckner
35-AV-1	Wayne	Sec. 33 T2S R8E	Barnhill
18-SG-1	Franklin	Sec. 27 T7S R4E	Thompsonville
ISGS-151	Jasper	Sec. 35 T8N R10E	Hidalgo S.
ISGS-129	Wayne	Sec. 11 T2S R6E	Flora City Southeast
40-SG-1	Edwards	Sec. 36 T2N R10E	Parkersburg C.
ISGS-128	Jefferson	Sec. 6 T2S R4E	Divide South
53-SG-1	Clay	Sec. 5 T5N R7E	Sailor Springs C.
ISGS-137	Jasper	Sec. 17 T6N R10E	Clay City C.
ISGS-136	Richland	Sec. 30 T3N R10E	Calhoun C.
ISGS-135	Jasper	Sec. 3 T5N R9E	Bogota South
ISGS-126	Jefferson	Sec. 22 T2S R4E	Bluford
ISGS-134	Jasper	Sec. 10 T5N R9E	Bogota South
ISGS-132	Edwards	Sec. 20 T1S R10E	Bone Gap West
54-SG-1	Jasper	Sec. 32 T6N R10E	Clay City C.
ISGS-133	Wabash	Sec. 16 T4S R13W	Sumner
72-SG-1	Coles	Sec. 10 T11N R7E	Mattoon
ISGS-131	Edwards	Sec. 22 T1S R10E	Bone Gap West
58-STL-1	Jasper	Sec. 33 T7N R10E	Clay City C.
039-Son-1	De Witt	Sec. 34 T21N R4W	McKinley
Devonian			
147-D-1	Piatt	Sec. 8 T19N R5E (NE)	Deland
147-D-2	Piatt	Sec. 8 T19N R5E (SW)	Deland
44-Dev-1	Clinton	Sec. 15 T1N R2W	Posey E.
L-Dev	Hamilton	Sec. 27 T6S R6E	Walpole
79-Dev-1	Christian	Sec. 16 T13N R1E	Assumption

Table 9 *continued*

Sample	County	Location	Field*
Devonian *continued*			
021-D-1	Christian	Sec. 27 T14N R3W	Edinburg S.
32-Dev-2	Washington	Sec. 9 T2S R2W	Beaucoup
33-Dev-2	Washington	Sec. 26 T1S R1W	Irvington
Silurian			
87-Sil-2	Sangamon	Sec. 19 T16N R3W	Dawson
87-Sil-1	Sangamon	Sec. 34 T16N R4W	Clear Lake East
80-Sil-1	Christian	Sec. 21 T14N R3W	Edinburg W.
26-Sil-2	Randolph	Sec. 16 T4S R5W	Tilden
88-Sil-1	Macon	Sec. 24 T17N R2E	Forsyth
BAO-2	Brown	Sec. 30 T1S R3W	Buckhorn C.
039-S-1	De Witt	Sec. 28 T21N R3E	Wapella
BAO-1	Brown	Sec. 31 T1S R3W	Buckhorn C.
80-Sil-3	Christian	Sec. 13 T15N R2W	Mt. Auburn
J-Sil-1	Adams	Sec. 36 T1S R5W	Kellerville
98-Sil-1	Logan	Sec. 7 T19N R3W	No field (wildcat)
49-Sil-4	Madison	Sec. 9 T4N R6W	Marine
79-Sil-1	Macon	Sec. 5 T15N R1E	Blackland
BAO-3	Brown	Sec. 34 T1S R4W	Buckhorn C.
F-Sil-1	Brown	Sec. 9 T2S R4W	Siloam
96-Sil-1	De Witt	Sec. 21 T21N R3E	Wapella
44-Sil-1	Clinton	Sec. 24 T1N R3W	Barteslo
Ordovician (Trenton/Galena)			
46-T-1	St. Clair	Sec. 34 T1N R10W	Dupo
43-T-2	Clinton	Sec. 35 T2N R1W	Centralia
25-T-1	Perry	Sec. 10 T4S R2W	Turkey Bend
33-T-2	Washington	Sec. 23 T1S RW	Irvington
33-T-1	Jefferson	Sec. 19 T1S R2E	Boyd
45-T-1	Madison	Sec. 16 T3N R6W	St. Jacob
90-T-1	Douglas	Sec. 9 T16N R8E	Hayes
73-T-1	Clark	Sec. 5 T11N R14W	Westfield
32-T-1	Washington	Sec. 21 T3S R2W	Posen
45-T-2	Madison	Sec. 27 T3N R6W	St. Jacob
50-T-1	Bond	Sec. 21 T6N R2W	Woburn

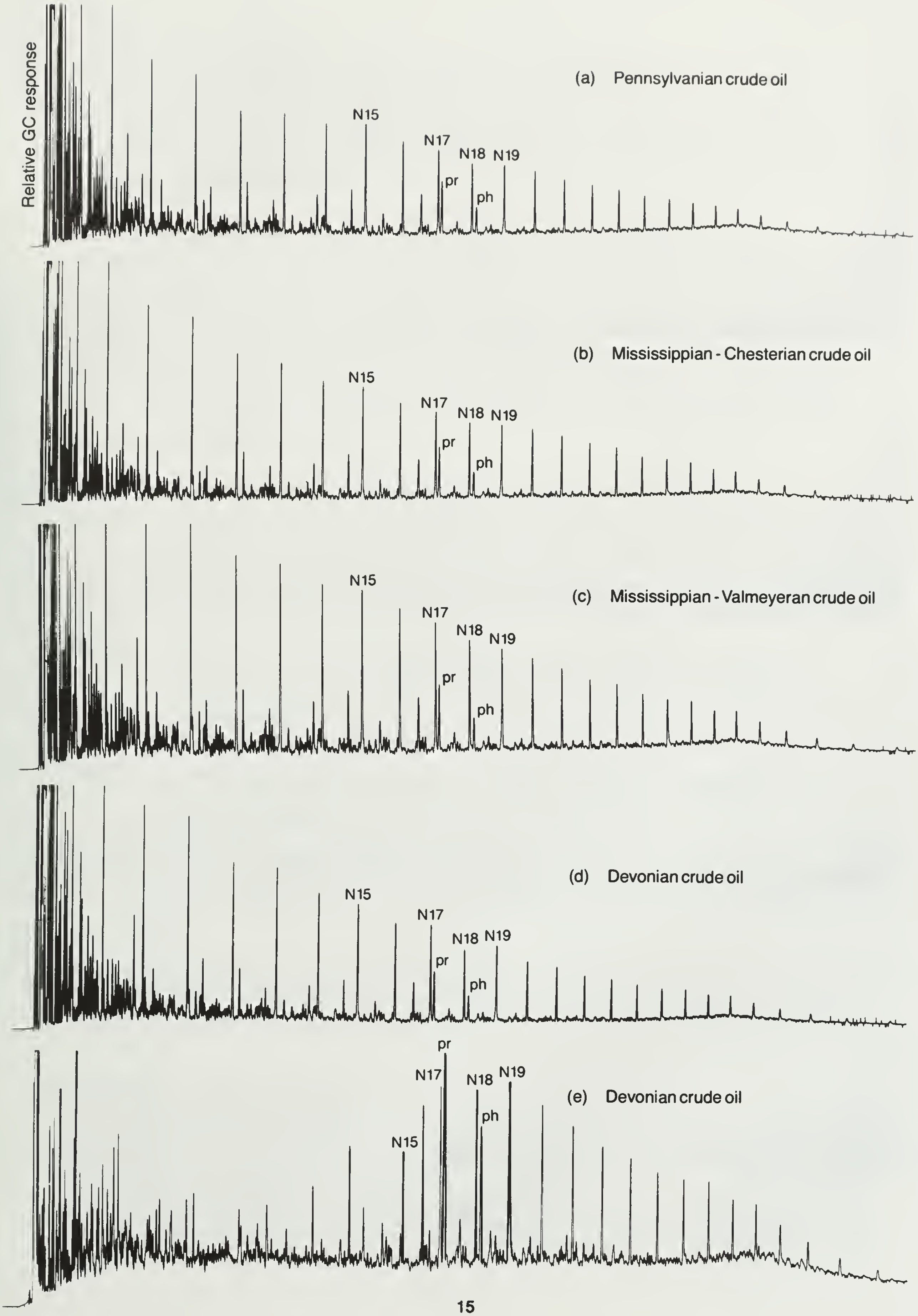
* C = consolidated

Silurian

Crude oils from Silurian reservoirs show three different distribution patterns (fig. 9a,b,c). The oil from Adams, Brown, Clinton, Christian, Macon, Madison, and Randolph Counties, Illinois (fig. 9a), has a GC fingerprint similar to that of the Pennsylvanian, Mississippian, and many Devonian crude oils (fig. 8). The GC fingerprint for the Silurian oil from Logan and De Witt Counties, Illinois (fig. 9b), has a bimodal *n*-alkane distribution that is similar to that of the Devonian oil from adjacent Piatt County, Illinois (fig. 8e). In the fingerprint (fig. 9c) for the Silurian oil from Sangamon County, Illinois, *n*-alkanes with odd numbers of carbon atoms are more abundant than those with even numbers, *n*-alkanes with n-C_{21-} are more abundant than those with n-C_{21+}, and concentrations of pristane and phytane are lower than other Silurian oils.

Figure 8 *(page 15)*

Typical GC fingerprints of whole crude oils from reservoirs in *(a)* Pennsylvanian (Bond County, IL); *(b)* Mississippian Chesterian (Clay County, IL); *(c)* Mississippian Valmeyeran (Coles County, IL); *(d)* Devonian (Bond County, IL); and *(e)* Devonian (Piatt County, IL). Peak numbers correspond to *n*-alkane carbon numbers (ex. N15 = n-C_{15}); pr = pristane; ph = phytane.


Relative GC response
(a) Pennsylvanian crude oil
N15
N17
N18
N19
pr
ph
(b) Mississippian - Chesterian crude oil
N15
N17
N18
N19
pr
ph
(c) Mississippian - Valmeyeran crude oil
N15
N17
N18
N19
pr
ph
(d) Devonian crude oil
N15
N17
N18
N19
pr
ph
(e) Devonian crude oil
pr
N17
N18
N19
ph
N15

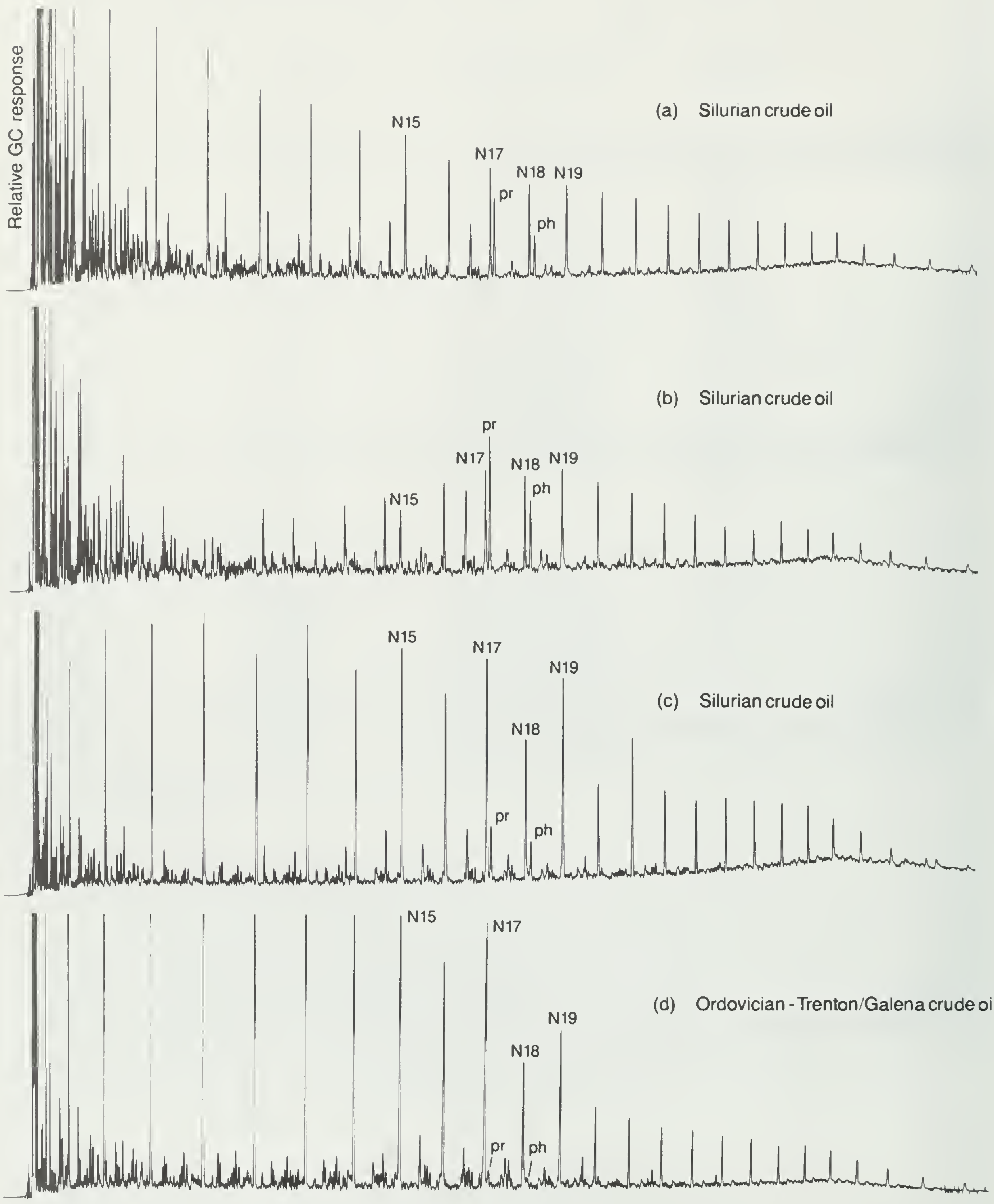


Figure 9 Typical GC fingerprints of whole crude oils from reservoirs in *(a)* Silurian (Adams County, IL); *(b)* Silurian (De Witt County, IL); *(c)* Silurian (Sangamon County, IL); and *(d)* Ordovician (Macon County, IL). Peak numbers correspond to *n*-alkane carbon numbers (ex. N15 = n-C_{15}), pr = pristane; ph = phytane.

Ordovician (Trenton/Galena)

The oil from Ordovician (Trenton/Galena) reservoirs (fig. 9d) shows a general aliphatic-hydrocarbon composition pattern that is similar to many Cambro-Ordovician oils of North America. These oils contain *n*-alkane odd-carbon predominance up to n-C_{19}, very low concentrations of pristane and phytane, and low concentrations of higher-molecular-weight *n*-alkanes (n-C_{20+}) (Martin et al. 1963, Vogler et al. 1981, Illich and Grizzle 1983, Reed et al. 1985, Longman and Palmer 1987).

A slight variation of the GC fingerprint observed in two of the Ordovician oils (from Douglas and Clark Counties, Illinois) shows odd-carbon predominance up to n-C_{21} and a slightly higher n-C_{20+} concentration. This pattern of odd-carbon *n*-alkanes predominating up to n-C_{21} is quite similar to the Silurian oils (fig. 9c) from Sangamon County. However, Silurian oils have relatively higher concentrations of pristane, phytane, and n-C_{20+} than the Trenton/Galena oil. In their study of the GC fingerprints of 15 Middle to Upper Ordovician oils from fields in the Midcontinent region of the United States, Longman and Palmer (1987) showed that Ordovician oils can be divided into two groups, with one group containing relatively higher concentrations of pristane, phytane, and n-C_{20+} *n*-alkanes than the other (M. W. Longman, personal communication 1987).

The oils studied can be classified into four types on the basis of the observed GC fingerprints.

Type A oils from Pennsylvanian, Mississippian, some Devonian (Christian, Clinton, Hamilton, and Washington Counties, Illinois), and some Silurian (Adams, Brown, Clinton, Christian, Macon, Madison, and Randolph Counties, Illinois) reservoirs have fingerprints showing moderate amounts of pristane and phytane and a progressive decrease in the amounts of *n*-alkanes with increasing molecular weight (figs 8a-d, 9a).

Type B oils from some Devonian (Piatt County) and some Silurian (Logan and De Witt Counties) reservoirs show bimodal normal-alkane distributions. In the lower molecular-weight region, mainly light hydrocarbons ($<n$-C_{11-}) are observed; whereas in the higher-molecular-weight region, *n*-alkanes in the n-C_{16} to n-C_{23} range predominate and pristane and phytane concentrations are high (pr$>n$-C_{17}) (figs. 8e, 9b).

Type C oils from some Silurian reservoirs in Sangamon County show progressively decreasing amounts of *n*-alkanes with odd-carbon preference in the n-C_{11} to n-C_{21} range, and moderate amounts of pristane and phytane (fig. 9c).

Type D oils from Ordovician Trenton/Galena reservoirs exhibit *n*-alkane distributions with odd-carbon predominance (up to n-C_{19}), a low concentration of higher molecular-weight *n*-alkanes (n-C_{20+}), and very low concentrations of pristane and phytane (fig. 9d).

Ratios of pristane (pr) to phytane (ph), pr/n-C_{17}, and ph/n-C_{18} for the oils were calculated using peak heights; they are tabulated in appendix E. These values provide a numerical comparison in addition to the qualitative GC fingerprints comparison, which will be discussed later.

OIL-SOURCE CORRELATION BY GAS CHROMATOGRAPHIC ANALYSIS

This preliminary oil-source correlation in the Illinois Basin is based upon comparisons between the GC fingerprints of aliphatic hydrocarbons in crude-oils with those from solvent-extracted shales. The pulverized shales were extracted with benzene for 24 hours in a Soxhlet apparatus. The resultant extracts were then separated into aliphatic, aromatic, and NOS-polar fractions using silica/alumina column chromatography. The comparison of these GC fingerprints of aliphatic hydrocarbons is limited to those greater than n-C_{15} because of the unavoidable evaporation of low-boiling components from the shales during the solvent-extraction processes.

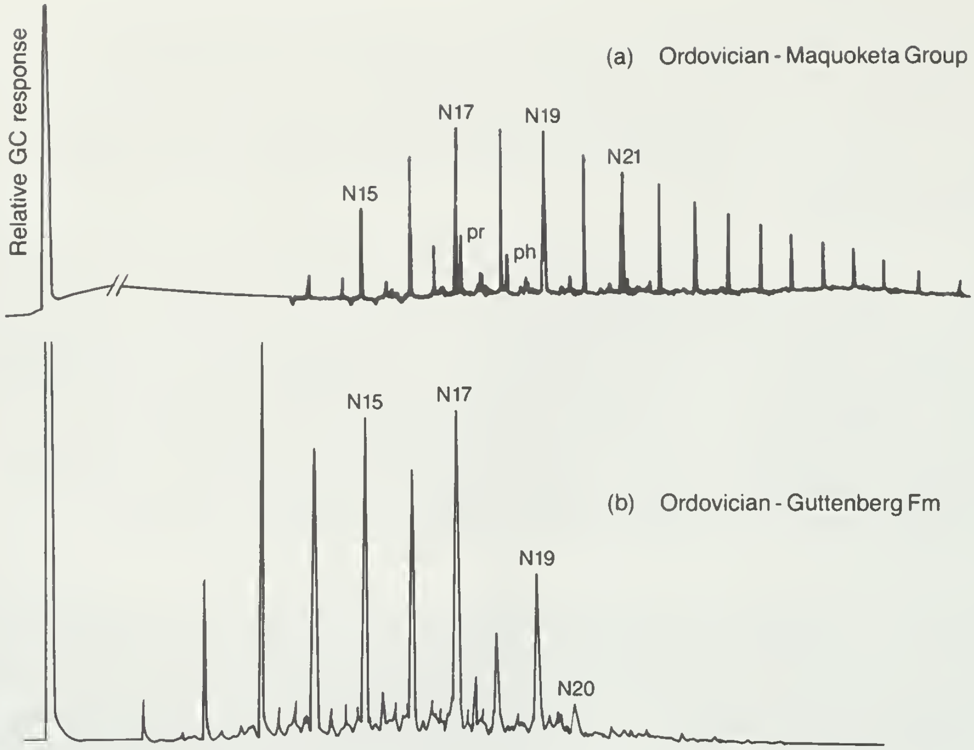


Figure 10 Typical GC fingerprints of the extractable aliphatic hydrocarbons of *(a)* Maquoketa Group and *(b)* Guttenberg formation. Peak numbers correspond to *n*-alkane carbon numbers (ex. N15 = n-C_{15}); pr = pristane; ph = phytane.

Aliphatic Hydrocarbons from Shales Extracts

Gas chromatograms of the aliphatic fractions from selected shales of the Maquoketa Group and the Guttenberg Formation are shown in figure 10. The GC fingerprint of the aliphatic hydrocarbons for the Maquoketa (table 2, Maquo-8) shows a distribution of *n*-alkanes (from n-C_{17} and n-C_{18} to higher-molecular-weight alkanes) that decreases smoothly with increasing molecular weight, small amounts of pristane and phytane, and pr/n-C_{17} and ph/n-C_{18} peak height ratios of 0.38 and 0.28, respectively. This sample had 0.80 percent TOC. However, the GC fingerprint of the aliphatic hydrocarbons from the Guttenberg Formation, which possessed 28.70 percent TOC (table 1, Gutt-2), is quite different. The pattern exhibits an odd-carbon predominance starting with n-C_{13} and very small amounts of pristane, phytane, and n-C_{20+}; characteristics that are similar to the observations of Fowler and Douglas (1984), Reed et al. (1985), and Longman and Palmer (1987). Fowler and Douglas (1984) described four organic-rich Ordovician rocks. Reed et al. (1985), and Longman and Palmer (1987) found that Ordovician oils have a characteristic odd-carbon predominance in the n-C_9 to n-C_{19} range and low concentrations of pristane, phytane, and n-C_{20+}.

Cores from the New Albany Group in the Illinois Basin, which are from a northwest-trending transect, were studied for solvent-extractable organic composition (Chou and Dickerson 1985). The cores used were 04IL, 06IL, 02IL, 13IL, and 01KY (fig. 3). Differences in the concentration of *n*-alkanes relative to the concentration of isoprenoids (pristane and phytane) were observed for shales from different locations. Typical gas chromatograms of the aliphatic hydrocarbons for shales from western Illinois (Henderson County, 04IL) and southeastern Illinois (Wayne County, 13IL) are shown in figure 11 (Chou and Dickerson 1985). Western

Table 10 Organic geochemical parameters (ratios of pr/n-C_{17} and ph/n-C_{18}), TOC, shale unit, and depths (below surface) of 23 samples from the New Albany Group (04IL, 06IL, 02IL, 3IL, and 01KY) (after Chou and Dickerson 1985)

Sample no.	Depth, ft	TOC %	Mean vitr. refl.	pr/n-C_{17}	ph/n-C_{18}	Shale unit*
04IL05C1	363.30	0.84		0.69	0.46	HBSV
08C1	393.10	0.82		0.48	0.42	HBSV
12C1	433.30	0.91		1.68	1.01	HBSV
14C1	453.05	2.96	0.48	2.57	1.95	HBSV
15C1	463.20	1.83		1.81	1.12	GRCK
16C1	473.10	2.75	0.47	2.23	1.98	GRCK
17C1	482.35	3.55	0.41	2.24	1.22	GRCK
20C1	513.35	5.31		1.82	1.24	SDCK
24C1	553.40	2.18		3.00	1.85	SDCK
06IL18C1	1,073.30	4.14	0.50	1.42	1.00	HBSV
19C1	1,083.20	6.11	0.42	1.40	1.00	GRCK
20Cl	1,093.35	9.52	0.41	1.20	1.00	GRCK
25C1	1,143.50	2.81	0.41	1.34	0.91	SDCK
02IL01C1	3,011.40	1.61	0.67	1.00	0.69	HBSV
04C1	3,053.00	8.51		0.76	0.56	GRCK
13IL06C2	5,069.60	5.31	0.78	0.38	0.31	GRCK
09C1	5,090.30	8.35		0.43	0.31	GRCK
09C2	5,094.00	8.35	0.68	0.43	0.23	GRCK
17C3	5,173 to 5,179	8.46	0.74	0.39	0.28	GRCK
01KY03C2	2,224.00	8.15	0.51	0.58	0.43	GRCK
07C1	2,260.30	11.95	0.39	0.61	0.47	SELM
10C1	2,290.75	9.23	0.52	0.81	0.65	SELM
12C1	2,310.50	5.67	0.79	0.52	0.38	BLCR

* Shale units: HBSV, Hannibal and Saverton; GRCK, Grassy Creek; SDCK, Sweetland Creek; SELM, Selmier; and BLCR, Blocher.

Illinois shales contained a large amount of pristane and phytane relative to those in southeastern Illinois. A smooth progressive decrease in the content of n-alkanes with increased molecular weight (n-C_{17} and greater) was observed in all the rocks of the New Albany Group.

Table 10 lists the peak-height ratios of pr/n-C_{17} and ph/n-C_{18}, TOC, and depths for samples from several cores in the Illinois Basin. Shales from a western Illinois core, 04IL (Henderson County), and a west-central core, 06IL (Tazewell County), which are relatively less mature (lower vitrinite reflectance, shallower burial), have comparatively high pr/n-C_{17} and ph/n-C_{18} ratios. Excluding the two shallowest samples, the pr/n-C_{17} peak height ratios range from 1.34 to 3.00 and the ph/n-C_{18} ratios range from 0.91 to 1.98. In contrast, these ratios are relatively low for more mature shales (higher vitrinite reflectance) from south-central Illinois (Effingham County, 02IL), southeastern Illinois (Wayne County, 13IL), and adjacent western Kentucky (Christian County, 01KY). The pr/n-C_{17} ratios in these three cores range from 0.38 to 1.00 and the ph/n-C_{18} ratios range from 0.23 to 0.69.

In other words, the percentages of n-alkanes increase relative to isoprenoids (pr and ph) with increasing thermal maturity and depth of burial (table 10). With the exception of the two shallowest samples (04IL05C1 and 08C1), pr/n-C_{17} ratios decrease as the burial depth of the unit (or thermal maturity of the shale) increases from western Illinois (433 to 563 ft), to central Illinois (1,032 to 1,143 ft), to the deepest part of the basin in southeastern Illinois (3,011 to

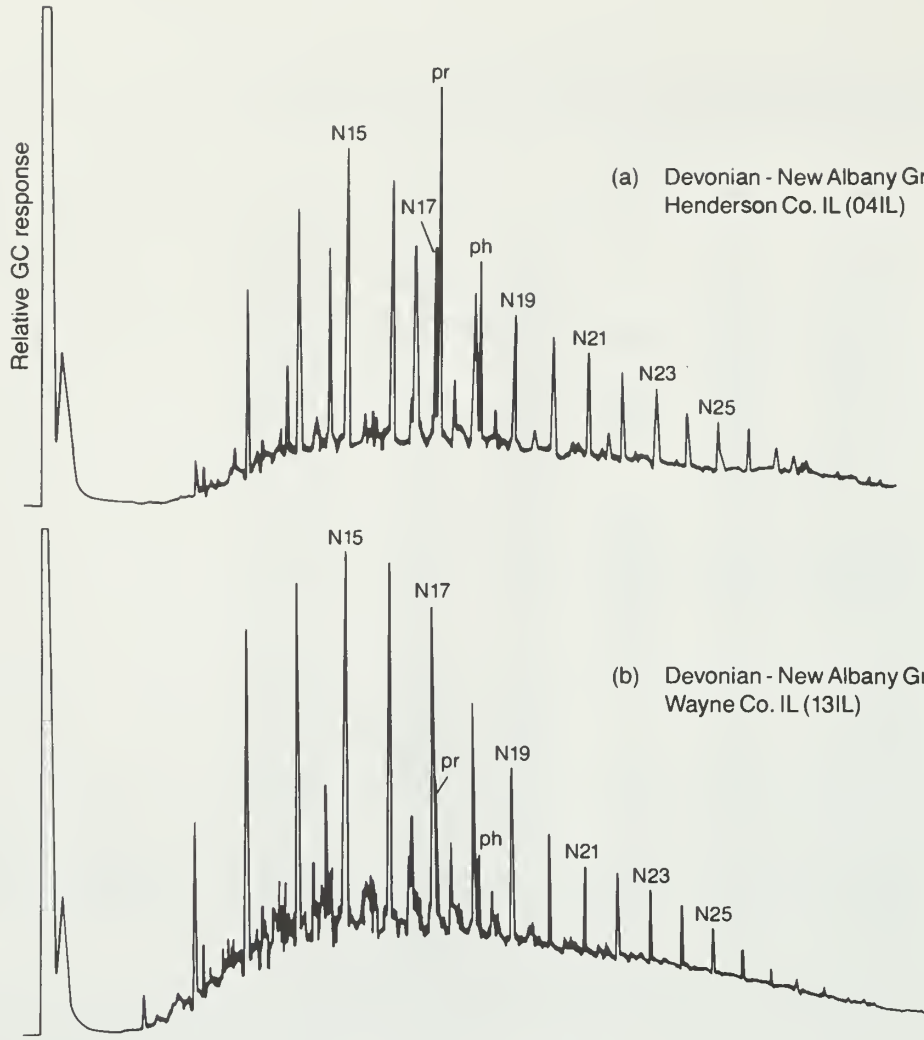


Figure 11 Typical GC fingerprints of the aliphatic hydrocarbons of the New Albany Group from *(a)* western Illinois and *(b)* southeastern Illinois. Peak numbers correspond to *n*-alkane carbon numbers (ex. N15 = n-C_{15}); pr = pristane; ph = phytane.

5,178 ft, fig. 12). Farther south, a slight increase in the pr/n-C_{17} ratio is caused by a shallower burial depth for the Kentucky core (Christian County, 01KY).

The Anna Shale, which was deposited in a marine environment, contains large amounts of pristane and phytane and relatively small amounts of normal alkanes. The Energy Shale, which was deposited in a nonmarine environment, contains relatively small amounts of pristane and phytane and large amounts of *n*-alkanes (fig. 13). The distribution of *n*-alkanes shows two distinct areas of concentration, one of lower molecular weight (n-C_{15} through n-C_{20}) and the other of higher molecular weight (n-C_{21} through n-C_{27}). In the lower-molecular-weight region, n-C_{17} is predominant, whereas in the higher-molecular-weight region, n-C_{23} and n-C_{24} are predominant. Hunt (1979, tables 4 and 5) suggested that a predominance of *n*-alkanes in the n-C_{21} to n-C_{26} range is indicative of a brackish or marine-coastal plant source.

The pr/n-C_{17} and ph/n-C_{18} ratios of nine shale samples from the Carbondale Formation are listed in table 11 (Chou et al. 1987). The marine-deposited Anna Shale generally has lower pr/ph ratios, higher pr/n-C_{17} ratios, and higher ph/n-C_{18} ratios than the nonmarine to brackish-deposited Energy Shale. Analyses of more samples from known depositional environments are

Table 11 Organic geochemical parameters of selected samples from the Anna and Energy Shale Members of the Pennsylvanian Carbondale Formation*

Sample	pr/ph	pr/n-C_{17}	ph/n-C_{18}
Anna-1	0.9	3.3	3.4
Anna-2	0.9	2.2	3.1
Anna-3	1.1	2.3	2.6
Anna-4	1.0	2.0	2.4
Anna-5	1.5	0.9	0.6
Energy-1	1.8	0.8	0.5
Energy-2	2.0	1.3	0.9
Energy-4	1.4	1.1	0.8
Energy-5	2.0	1.2	0.7

* For sample locations, see table 3.
† An altered, possibly bioturbated sample.

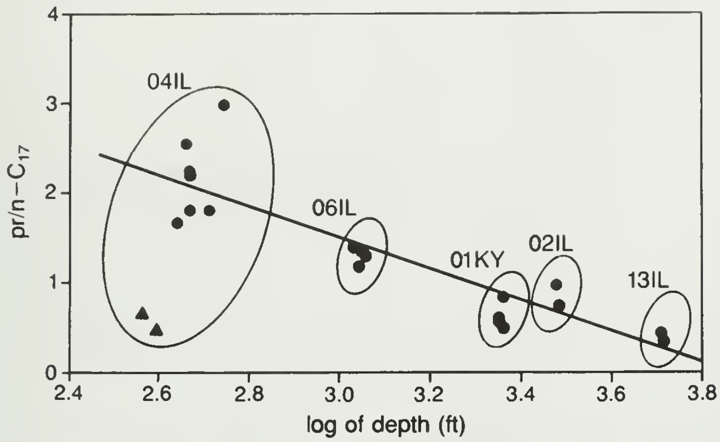


Figure 12 Relationship between the ratio of pr/n-C_{17} and depth of shale from the New Albany Group. (The two shallowest shale samples are indicated by triangles.)

needed to determine whether the differences between these ratios are directly related to the depositional environment of the organic matter.

Comparison of Gas Chromatographic Fingerprints Between Crude Oil and Shale

The aliphatic hydrocarbon compositions of the extracts from rocks of the New Albany Group in southeastern Illinois (fig. 11b) are similar to the compositions of crude oils from younger reservoirs including Pennsylvanian, Mississippian, many Devonian, and many Silurian oils (fig. 8a–c). They all have smooth, progressive decreases in the quantities of n-alkanes with increasing molecular weight, moderate amounts of pristane and phytane, and similar pr/n-C_{17} and ph/n-C_{18} ratios.

The pr/n-C_{17} and ph/n-C_{18} ratios for the oils (appendix E) are plotted by type (fig. 14). For the oils from younger reservoirs (type A), the pr/n-C_{17} ratios range from 0.4 to 1.0 and the ph/n-C_{18} ratios range from 0.3 to 0.8. These ratios are similar to those for the New Albany in the southeastern part of the Illinois Basin (02IL, 13IL, 01KY in table 10; fig. 12), but are different from those of other areas. The pr/n-C_{17} ratios range from 0.38 to 1.00 and the ph/n-C_{18} ratios range from 0.23 to 0.69 for the New Albany in the southeastern part of Illinois, whereas for the New Albany in other areas (04IL and 06IL in table 10) the pr/n-C_{17} ratios range from 1.34 to 3.00 and the ph/n-C_{18} ratios range from 0.91 to 1.98.

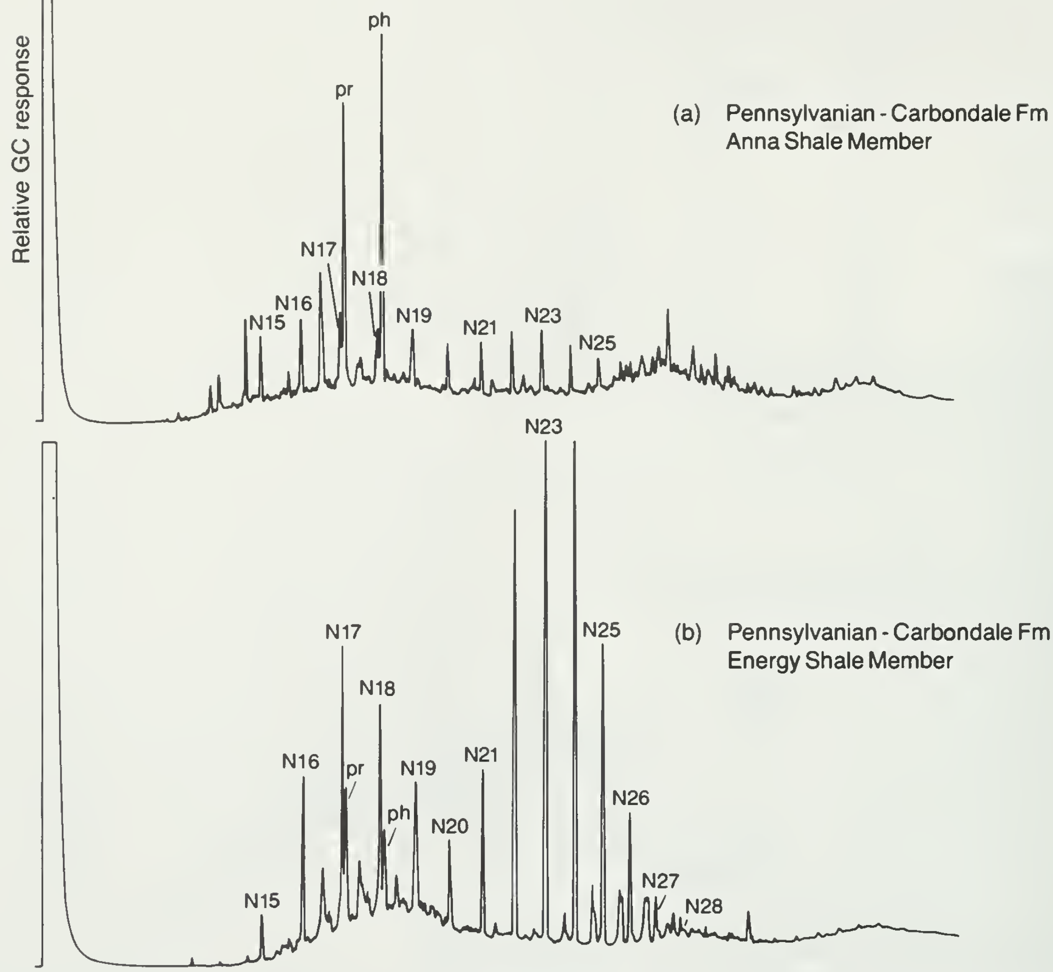


Figure 13 Typical GC fingerprints of the extractable aliphatic hydrocarbons from the *(a)* Anna Shale Member and *(b)* Energy Shale Member of the Pennsylvanian Carbondale Formation. Peak numbers correspond to *n*-alkane carbon numbers (ex. N15 = n-C_{15}); pr = pristane; ph = phytane.

This similarity between the compositions of the shale extracts and the oils confirms the pyrolysis study in this report, a petrographic study by Barrows and Cluff (1984), and a discussion by Demaison (1984) that suggest oil generation and subsequent expulsion occurred in the southeastern parts of Illinois where present burial depths are between about 3,000 and 5,000 feet (900 and 1,500 m) and vitrinite reflectance values are between 0.6 and 0.7.

The GC fingerprint patterns of oils from Ordovician Trenton/Galena reservoirs, Silurian reservoirs in Sangamon County, Illinois, and extracts of shales of the Guttenberg Formation (figs. 9d,c and 10b) are different from those of the oils of younger reservoirs, but similar to those of many "Ordovician-type" oils of North America that have possible source beds of Middle Ordovician shale (Illich and Grizzle 1983, Reed et al. 1985, Hatch et al. 1987, Longman and Palmer 1987). The similarities among the Silurian oil from Sangamon County, Illinois, the Trenton/Galena oil, and the extracts of the Guttenberg Formation suggest that oils in Trenton/Galena reservoirs and some Silurian reservoirs in the Illinois Basin may originate from Guttenberg or other Ordovician shales. The GC fingerprint patterns so far obtained for the Ordovician Maquoketa Group shales do not match the Trenton/Galena oils and cannot be their source.

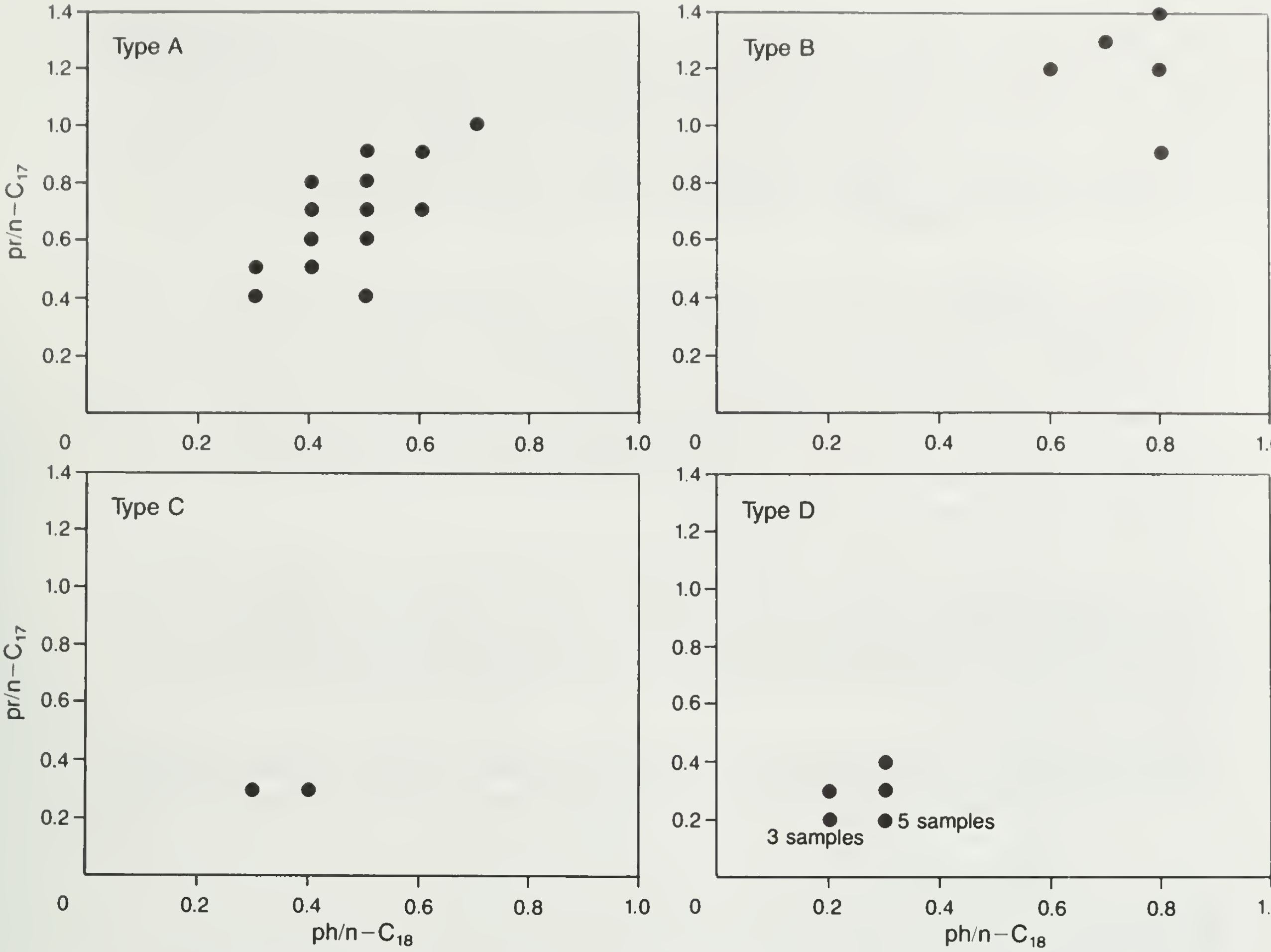


Figure 14 Distribution of pr/n-C_{17} and ph/n-C_{18} ratios for the crude oils by type.

Extracts from the Anna and Energy Shale Members (Pennsylvanian Carbondale Formation; fig. 13) are not similar to the composition of any crude oils analyzed. This information, added to the results of pyrolysis analyses that indicate a very low level of thermal maturity for these shales, clearly indicates that the Anna and Energy Shales are not sources for any of the crude oils.

SUMMARY AND CONCLUSIONS

Most of the shales from four stratigraphic intervals examined have TOC values higher than the critical lower limit (0.5% for shale) cited by Tissot and Welte (1984) for potential petroleum source rocks.

Pyrolysis (Rock-Eval) analysis indicates excellent oil-source potential for the Guttenberg Formation, limited oil-source potential for shales of the Maquoketa Group, a mixed source potential for oil and gas for the shales of the New Albany Group, and thermal immaturity for the Pennsylvanian Anna and Energy Shale Members.

The New Albany Group in western Illinois contains immature kerogen (types I, II, and III). In eastern and southeastern Illinois, it contains a greater abundance of marginally mature to mature (type II) kerogen, an indication of good hydrocarbon-source potential in the oil-generation zone. In extreme southern Illinois (Hicks Dome area) the New Albany contains overmature (type III) kerogen with poor oil-generative potential, but has some potential for gas generation.

Four characteristic GC fingerprint patterns were observed in the crude oils analyzed: type A exhibits a gradually decreasing *n*-alkane distribution and moderate amounts of pristane and phytane; type B shows a bimodal *n*-alkane distribution; type C shows a decreasing *n*-alkane distribution with odd-carbon preference in the n-C_{11} to n-C_{21} range and contains moderate amounts of pristane and phytane; and type D exhibits an *n*-alkane distribution with odd-carbon predominance (up to n-C_{19}), a low concentration of higher-molecular-weight normal (n-C_{20+}) alkanes, and very low concentrations of pristane and phytane.

Stratigraphic variations of crude oils, as reflected in GC fingerprint patterns, suggest that type A is common for crude oils from younger reservoirs, whereas type D is characteristic of Trenton/Galena (Ordovician) oils. Type B oils are relatively rare among the samples studied. This fingerprint might be the result of bacterial degradation, but the exact cause of this variation is not known and needs further investigation. Type C oils are similar to Trenton/Galena oils, but they have a slightly different range of odd-carbon predominance and slightly higher concentrations of pristane, phytane, and n-C_{20+}. The general similarity between the type C and D oils implies that they may have similar sources.

Illinois crude oils have at least two distinct sources, one originating from sources younger than Ordovician age, probably shales of the New Albany Group (Devonian-Mississippian) and the other probably originating from Ordovician rocks. The GC fingerprints suggest that the Guttenberg Formation or perhaps some similar Ordovician source rock is a likely source for at least some Ordovician oil.

Additional studies are needed to assess the source-rock potential of the Maquoketa Group and the Guttenberg Formation across the Basin and to further define oil-source correlation trends.

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APPENDIX A

Total organic carbon data of 317 shale samples from Maquoketa Group (Stevenson and Dickerson 1971)

Well	County	Location	Depth (ft)	TOC (%)
#1 Koss	Effingham	Sec. 12 T6N R4E	4,637–4,704	1.80
#1 McWhorter	Effingham	Sec. 15 T6N R6E	5,058–5,275	1.26
#1 Genaust	Effingham	Sec. 18 T7N R6E	4,667–4,880	2.38
#1 Merryman	Fayette	Sec. 36 T4N R1W	3,770–3,946	1.46
#1 Gehle	Fayette	Sec. 13 T5N R2E	4,224–4,427	1.83
#1 Jerome	Fayette	Sec. 32 T6N R2E	4,130–4,344	1.41
#1 Dugan	Fayette	Sec. 23 T6N R1W	3,545–3,737	1.12
#1 Stokes	Fayette	Sec. 7 T8N R1W	3,296–3,505	5.01
#6-D Brauer	Fayette	Sec. 21 T8N R3E	3,608–3,824	1.10
#1 Weaber-Horn	Fayette	Sec. 28 T8N R3E	3,599–3,822	0.55
#12 Buzzard	Fayette	Sec. 29 T8N R3E	3,601–3,827	2.75
#1 Dambocher	Sangamon	Sec. 15 T13N R5W	1,872–2,076	1.92
#1 Malmsbury	Sangamon	Sec. 22 T13N R7W	1,604–1,799	4.47
#1 Clayton	Sangamon	Sec. 8 T14N R4W	1,972–2,183	1.18
#1 Dierks	Sangamon	Sec. 5 T15N R3W	1,920–2,122	3.09
#1 Thorton	Sangamon	Sec. 23 T15N R7W	1,580–1,752	3.03
#1 Acox	Sangamon	Sec. 32 T16N R3W	1,984–2,180	5.79
#1 Spitzer	Sangamon	Sec. 4 T16N R6W	1,500–1,698	3.37
#1 Tolan	Sangamon	Sec. 33 T17N R6W	1,530–1,726	2.23
#1 Mundhenke	Christian	Sec. 5 T11N R3W	2,408–2,614	1.55
#1 Johnson	Christian	Sec. 27 T12N R2W	2,795–3,005	1.14
#34 Lawrence	Christian	Sec. 9 T13N R1E	2,692–2,896	0.82
#1 Ettinger	Christian	Sec. 8 T13N R1W	2,582–2,760	1.47
#1 Peabody	Christian	Sec. 32 T13N R3W	2,250–2,456	2.43
#1 Butler "B"	Christian	Sec. 13 T13N R4W	2,145–2,356	3.17
#1 Gordon	Christian	Sec. 21 T14N R1E	2,696–2,902	1.24
#1 Morgot	Christian	Sec. 10 T14N R2W	2,286–2,497	3.50
#1 Butcher	Christian	Sec. 21 T15N R1W	2,226–2,472	1.80
#1 Copenbarger	Christian	Sec. 27 T16N R1W	2,098–2,295	3.49
#1 Wilson	Randolph	Sec. 3 T4S R5W	3,000–3,140	0.92
#1 Guebert	Randolph	Sec. 7 T4S R6W	1,964–2,128	0.51
#1 Rehmer	Randolph	Sec. 19 T4S R7W	1,615–1,755	0.80
#1 Schmell	Randolph	Sec. 28 T4S R7W	1,627–1,756	0.38
#1 Hartman	Randolph	Sec. 33 T4S R7W	1,627–1,752	0.37
#2 Temple	Randolph	Sec. 6 T5S R8W	2,747–2,908	1.00
#1 Cassoutt	Randolph	Sec. 16 T7S R7W	1,404–1,555	0.49
#1 Plocker	Madison	Sec. 10 T3N R5W	–2,769	2.92
#1 Leder	Madison	Sec. 12 T3N R6W	–2,510	1.51
#1 Keller	Madison	Sec. 8 T3N R8W	–1,680	0.54
#1 Hessel	Madison	Sec. 11 T3N R9W	–1,495	0.72
#1 Ambuehl	Madison	Sec. 20 T4N R5W	–2,708	1.29
#1 Brown	Clinton	Sec. 12 T1N R1W	3,845–4,017	2.03
#1 Simonton	Clinton	Sec. 26 T1N R3W	3,475–3,648	0.46
#1 Haukap	Clinton	Sec. 15 T1N R4W	3,092–3,248	0.64
#1 Winkler et al.	Clinton	Sec. 5 T1N R5W	2,623–2,740	0.53
#1 Hoffman	Clinton	Sec. 26 T2N R1W	3,813–3,994	1.13
#1 Wainecke	Clinton	Sec. 17 T2N R3W	3,887–3,267	0.81
#1 Breese-Trenton	Clinton	Sec. 23 T2N R4W	2,990–3,169	1.06
#1 Twiss	Clinton	Sec. 23 T2N R5W	2,773–2,944	0.58
#1 Williams	Clinton	Sec. 1 T3N R1W	3,750–3,939	0.84
#1 Seifert	Clinton	Sec. 21 T3N R2W	3,376–3,569	0.69
#1 Schrage	Clinton	Sec. 17 T3N R4W	2,770–2,933	1.14
#1 Freidrich	Clinton	Sec. 7 T1S R5W	2,545–2,694	0.37
#1 Grathwahl	Washington	Sec. 34 T1N R1W	4,012–4,210	0.90

Appendix A *continued*

Well	County	Location	Depth (ft)	TOC (%)
#10 Stanton	Washington	Sec. 6 T1S R1W	4,077–4,270	0.88
#3 Baldwin	Washington	Sec. 5 T1S R4W	3,240–3,398	0.84
#1 Brueggemann	Washington	Sec. 1 T1S R5W	2,647–2,784	2.43
#1 Tucker	Washington	Sec. ? T2S R1W	4,197–4,368	0.86
#1 Hosemeir	Washington	Sec. ? T2S R2W	3,929–4,079	0.77
#1 Droege	Washington	Sec. 1 T2S R4W	3,083–3,207	1.39
#1 Kitowski	Washington	Sec. 1 T3S R2W	3,728–3,907	0.55
#1 Hunleth	Washington	Sec. 9 T3S R4W	3,109–3,267	0.61
#1 Margaret	Washington	Sec. ? T3S R5W	2,610–2,759	1.14
#1 City Park	St. Clair	Sec. 34 T2N R9W	1,237–1,337	2.94
#1 Grand Coles	St. Clair	Sec. 15 T1S R7W	1,908–2,032	0.49
#1 Heap	St. Clair	Sec. 29 T1S R8W	1,205–1,355	3.12
#1 Scharf	St. Clair	Sec. 4 T1S R9W	1,066–1,213	0.63
#1 Reichert	St. Clair	Sec. 3 T1S R10W	640–778	4.73
#1 Lange	St. Clair	Sec. 24 T2S R6W	2,500–2,640	0.48
#1 Harbaugh	St. Clair	Sec. 28 T2S R8W	1,224–1,356	1.70
#1 Keim	St. Clair	Sec. 3 T2S R9W	1,045–1,180	3.26
#1 Schickedanze	St. Clair	Sec. 12 T3S R6W	2,537–2,684	0.44
#1 Morris	St. Clair	Sec. 14 T1N R6W	2,546–2,680	1.14
#1 Schneppe	St. Clair	Sec. 5 T1N R8W	1,706–1,861	1.47
#1 Sparks	St. Clair	Sec. 2 T1N R10W	800–955	1.69
#1 Harms	St. Clair	Sec. 31 T2N R6W	2,195–2,334	0.53
#6 Elam	Bond	Sec. 3 T6N R3W	3,002–3,210	0.83
#1 Vaughn	Bond	Sec. 14 T6N R3W	2,942–3,110	0.74
#4 Roby-Griffin	Bond	Sec. 16 T6N R4W	2,433–2,607	1.76
#1 Saathoff	Bond	Sec. 12 T6N R5W	2,423–2,605	0.78
#1 Blankenship–Stonebamer	Bond	Sec. 34 T7N R2W	2,905–3,111	0.77
#1 Acconero	Bond	Sec. 26 T4N R4W	2,877–3,066	1.18
#1 Bauer	Bond	Sec. 20 T5N R2W	3,205–3,384	0.82
#1 Tomberlin	Coles	Sec. 21 T11N R10E	3,090–3,290	1.49
#1 Seaman	Coles	Sec. 35 T12N R7E	3,835–4,052	1.33
#1 Link	Coles	Sec. 9 T12N R14W	2,323–2,476	1.24
#1 Solheim-Pearce	Coles	Sec. 34 T13N R9E	2,770–2,988	1.31
#1 Van Tuyle	Coles	Sec. 6 T13N R14W	1,795–2,032	1.36
#1 Huffman	Coles	Sec. 19 T14N R8E	3,586–3,796	2.57
#1 Wesch	Coles	Sec. 21 T14N R9E	1,500–1,726	1.39
#1 Parkes	Coles	Sec. 21 T14N R10E	1,986–2,206	1.33
#1 Dittamore	Coles	Sec. 19 T14N R8E	1,889–2,002	1.49
#1 Jackson	Clark	Sec. 19 T10N R14W	2,414–2,675	1.11
#1 Shaver	Clark	Sec. 1 T10N R14W	2,615–2,857	1.22
#2 Harper	Clark	Sec. 5 T11N R14W	2,015–2,260	1.93
#1 Woodard	Clark	Sec. 32 T12N R14W	2,135–2,387	1.67
#1 Shore	Cumberland	Sec. 6 T10N R10E	2,994–3,246	1.79
#19 C.W. & F. Coal	Franklin	Sec. 36 T6S R2E	5,980–6,105	1.19
#1 Hamp	Hardin	Sec. 30 T11S R8E	1,027–1,224	0.75
#1 Harsha	Jackson	Sec. 11 T7S R2W	4,414–4,543	0.76
#1 Leiner	Jackson	Sec. 20 T7S R4W	3,105–3,290	1.24
#1 Smith	Jackson	Sec. 9 T8S R3W	3,540–3,690	0.84
#1 Baysinger	Jackson	Sec. 32 T10S R3W	1,153–1,220	0.65
#12 Kasban	Jefferson	Sec. 8 T2S R1E	4,670–4,843	0.82
#20 Freidrich	Jefferson	Sec. 19 T1S R2E	4,794–4,954	0.77
#1 Souers	Lawrence	Sec. 20 T3N R12W	4,559–4,850	2.64
#23 Middaugh	Lawrence	Sec. 32 T4N R12N	4,075–4,370	0.66
#1 Davidson	Bond	Sec. 26 T5N R3W		1.78
#1 Maxwell	Crawford	Sec. 3 T5N R12W	3,978–4,280	0.95

Appendix A *continued*

Well	County	Location	Depth (ft)	TOC (%)
#1 Jones	Crawford	Sec. 12 T6N R12W	3,968–4,224	0.78
#1 Doty	Douglas	Sec. 8 T14N R8E	3,463–3,676	0.56
#1 Chapman	Macon	Sec. 4 T15N R1E	2,346–2,553	0.83
#1 Cook	Macon	Sec. 21 R15N R2E	2,815–3,031	1.31
#1 Graves	Macon	Sec. 3 T16N R1W	2,007–2,198	3.28
#1 Powers	Macon	Sec. 19 T17N R2E	2,347–2,540	1.38
#1 Menke	Macoupin	Sec. 12 T7N R7W	1,963–2,140	1.74
#1 Spence Bros.	Macoupin	Sec. 13 T8N R9W	1,493–1,663	0.87
#1 Austin	Macoupin	Sec. 9 T10N R6W	1,919–2,104	1.27
#1-B Lovelace	Macoupin	Sec. 8 T9N R7W	1,654–1,837	1.49
#1 Melin	Macoupin	Sec. 20 T10N R7W	1,676–1,860	1.96
#1 Clark	Macoupin	Sec. 11 T10N R9W	1,295–1,480	0.71
#1 Schmidt	Macoupin	Sec. 11 T12N R7W	1,666–1,858	1.64
#1 Butcher	Macoupin	Sec. 17 T12N R9W	1,185–1,365	5.83
#1 Miller	Macoupin	Sec. 26 T12N R6W	1,925–2,113	0.70
#1 Radfem	Macoupin	Sec. 11 T11W R9W	1,388–1,584	0.87
#1 Kalberkamp	Marion	Sec. 19 T1N R1E	3,852–4,048	0.93
#21 Tate	Marion	Sec. 5 T1N R2E	4,302–4,504	1.18
#1 Robinson	Marion	Sec. 4 T2N R2E	4,061–4,267	0.73
#22 Young	Marion	Sec. 20 T2N R2E	4,334–4,561	0.58
#2 Kieysteuber	Marion	Sec. 5 T3N R1E	3,850–3,985	0.86
#2 Nattier	Marion	Sec. 29 T4N R1E	3,767–3,957	1.08
#1 Babcock	Edgar	Sec. 4 T12N R13W	2,353–2,606	1.08
#1 Honnold	Edgar	Sec. 1 T13N R14W	1,927–2,165	0.93
#1	Edgar	Sec. 27 T15N R14W	1,534–1,761	0.94
#1 Martin	Douglas	Sec. 17 T14N R9E	1,418–1,645	2.18
#1 Eastin & Dallas	Douglas	Sec. 13 T16N R7E	2,935–3,131	0.93
#1 Genaust	Effingham	Sec. 18 T7N R6E	4,666–4,880	1.50
#1 McWhorter	Effingham	Sec. 15 T6N R6E	5,050–5,256	0.85
#1 Columbia Amer.	Monroe	Sec. 16 T1S R10W	1,003–1,145	0.84
#1 Krestner	Monroe	Sec. 20 T2S R9W	879–995	0.59
#1 Stumpf	Monroe	Sec. 31 T2S R10W	550–650	0.46
#1 Faas	Monroe	Sec. 32 T3S R10W	305–410	0.37
#1 Schuster	Monroe	Sec. 13 T3S R8W	1,595–1,738	0.54
#1 Aubuchon	Monroe	Sec. 1 T4S R9W	1,061–1,195	0.46
#1 Raybum	Monroe	Sec. 12 T4S R10W	812–904	0.86
#1 McReynolds	Moultrie	Sec. 18 T14N R4E	3,181–3,393	1.71
#1 Beachy	Moultrie	Sec. 13 T15N R6E	3,313–3,518	1.50
#1 Buhr	Perry	Sec. 22 T4S R1W	4,020–4,172	1.17
#1 Koul	Perry	Sec. 10 T4S R2W	3,745–3,937	0.49
#1 Ernest	Perry	Sec. 14 T4S R4W	3,469–3,644	0.72
#1 Webb	Montgomery	Sec. ? T7N R2W	2,996–3,207	0.88
#1 Manke	Montgomery	Sec. ? T7N R5W	2,303–2,490	0.96
#1 Taylor	Montgomery	Sec. 4 T7N R4W	2,465–2,658	0.55
#1 Singler	Montgomery	Sec. ? T8N R2W	2,959–3,171	1.24
#1 Lay	Montgomery	Sec. ?0 T8N R5W	2,234–2,430	0.97
#1 Traitt	Montgomery	Sec. ? T9N R3W	2,437–2,643	3.24
#1 Hopkins	Montgomery	Sec. 4 T9N R5W	2,296–2,500	1.50
#1 Faber	Montgomery	Sec. ? T10N R1W	3,144–3,360	1.05
#1 Janssen	Montgomery	Sec. ? T10N R2W	2,924–3,137	1.14
#1 Springfield	Montgomery	Sec. 2 T10N R3W	2,422–2,638	1.72
#1 Borgic	Montgomery	Sec. 6 T10N R4W	2,468–2,679	2.35
#1 Brandon	Montgomery	Sec. ? T10N R5W	2,207–2,405	1.31
#1 Long	Montgomery	Sec. 7 T11N R5W	2,160–2,539	1.05
#1 Lucas	Montgomery	Sec. S? T12N R5W	2,056–2,259	0.85
#1 Kelly	Piatt	Sec. 12 T18N R6E	1,658–1,864	1.44

Well	County	Location	Depth (ft)	TOC (%)
#1 Richey	Pulaski	Sec. 9 T15S R1E	2,380–2,565	0.82
#1 Roberts	Pulaski	Sec. 5 T16S R1W	1,665–1,875	0.89
#1 Hudson	Pulaski	Sec. 23 T16S R1W	1,316–1,524	0.73
#18-"B" Montgomery	Richland	Sec. 4 T3N R9E	5,642–5,903	0.79
Atlas Powder	Union	Sec. 33 T11S R3W	415–530	0.45
#1 Potoschnick	Union	Sec. 26 T13S R3W	355–471	1.05
#5 Fuherev	Wayne	Sec. 28 T1S R6E	6,273–6,348	1.16
#3 Billington	Wayne	Sec. 27 T1N R7E	6,057–6,247	2.10
#1 Graham	Greene	Sec. 19 T10N R11W	893–1,068	0.77
#1 Tunn	Greene	Sec. 14 T11N R12W	620–795	0.63
#1 Gilmort	Greene	Sec. 10 T12N R10W	936–1,115	1.73
#1 Vosseller	Greene	Sec. 8 T12N R13W	254–435	0.97
#1 Legate	Jersey	Sec. 2 T6N R13W	100–250	0.91
#1 Bielsmith	Jersey	Sec. 12 T7N R10W	1,191–1,359	0.51
#2 Reddish	Jersey	Sec. 18 T8N R13W	155–310	0.96
#1 Pearce	Jersey	Sec. 27 T8N R10W	1,140–1,300	0.98
#1 Mortlund	Calhoun	Sec. 26 T11S R2W	22–150	1.38
Pohlman	Calhoun	Sec. 18 T13S R1W	717–816	1.07
Jacobs	Calhoun	Sec. 24 T13S R2W	661–745	0.91
#1 De Groot	Cass	Sec. 30 T18N R8W	855–1,077	2.12
#1 Lambert	Cass	Sec. 6 T18N R10W	750–940	0.55
#1 Krohe	Cass	Sec. 12 T18N R11W	763–953	0.86
#1 Webel	Pike	Sec. 4 T3S R3W	618–790	1.43
#1 Weaver	Pike	Sec. 5 T3S R4W	445–637	0.66
#1 Bradshaw	Pike	Sec. 4 T4S R3W	345–515	1.35
#2 Kline Hill West	Pike	Sec. 7 T4S R4W	630–800	0.61
#1 Holmes	Pike	Sec. 11 T4S R5W	520–693	0.63
#1 Nichols	Pike	Sec. 12 T3S R2W	505–700	0.76
#1 Gorton	Pike	Sec. 35 T4S R7W	127–197	0.61
#1 Daniels	Pike	Sec. 18 T5S R4W	240–405	0.61
#1 Tittsworth	Pike	Sec. 13 T5S R6W	354–522	0.68
#1 Witty	Pike	Sec. 31 T6S R3W	138–300	0.71
#1 Adrian	Pike	Sec. 2 T6S R4W	358–522	0.60
#1 Crater	Pike	Sec. 19 T7S R2W	478–645	0.66
#1 Allison	Pike	Sec. 11 T7S R3W	235–394	0.83
Lot 43	Pike	Sec. 13 T6S R5W	355–521	0.61
#1 Allen	Morgan	Sec. 11 T13N R8W	1,333–1,515	0.42
#1 Hubbs	Morgan	Sec. 33 T14N R8W	1,357–1,545	0.55
#1 Dodsworth	Morgan	Sec. 24 T14N R9W	1,340–1,534	0.36
#1 Cleary	Morgan	Sec. 8 T15N R9W	1,045–1,242	1.24
#1 Wood Est.	Morgan	Sec. 26 T15N R10W	1,039–1,235	0.12
#1 Knack	Morgan	Sec. 29 T16N R12W	750–939	0.63
#1 Headlee	Champaign	Sec. 14 T20N R7E	1,180–1,355	0.59
#1 Graves	Champaign	Sec. 20 T21N R8E	1,107–1,307	0.59
#1 Talbot	Champaign	Sec. 26 T22N R10E	1,271–1,464	1.46
#1 McNally	Fulton	Sec. 19 T5N R4E	915–1,098	0.58
#1 Bradley	Fulton	Sec. 17 T6N R1E	654–853	4.19
#1 Elsbert	Fulton	Sec. 23 T6N R1E	738–915	0.57
Truax-Traer	Fulton	Sec. 33 T7N R3E	932–1,112	0.97
Midland Elec.	Fulton	Sec. 2 T8N R3E	880–1,064	0.66
Truax-Traer	Fulton	Sec. 33 T7N R31W	910–1,120	1.26
#1 Behreus	Iroquois	Sec. 7 T25N R13W	890–1,064	0.26
#1 Lockhart	Iroquois	Sec. 17 T26N R12W	740–903	0.70
#1 King	Iroquois	Sec. 16 T28N R10E	210–408	0.65
#1 Aleshire	McDonough	Sec. 29 T4N R4W	460–648	1.14
#1 Murray	McDonough	Sec. 8 T5N R4W	655–760	0.66

Well	County	Location	Depth (ft)	TOC (%)
City Well	McDonough	Sec. 33 T7N R1W	740–903	1.98
#1 Martin	Douglas	Sec. 17 T14N R9E	1,418–1,645	3.15
#1 Cole	Douglas	Sec. 23 T15N R8E	966–1,180	0.85
#1 Hilgenberg	Douglas	Sec. 10 T15N R9E	1,308–1,524	4.76
#1 Bass	Douglas	Sec. 27 T16N R8E	774–980	1.19
#1 Williams	Douglas	Sec. 14 T15N R9E	1,522–1,738	0.51
#1 Traws'	Douglas	Sec. 19 T16N R9E	1,063–1,271	0.77
#1 Jones	Crawford	Sec. 12 T6N R13W	3,968–4,224	0.66
#28 DuCommon	Crawford	Sec. 35 T6N R13W	3,570–3,859	0.59
#1 Rocke	Woodford	Sec. 18 T25N R1E	1,503–1,682	0.39
#1 Moreland	Woodford	Sec. 31 T26N R1E	1,448–1,635	0.31
#1 Lippert	De Witt	Sec. 1 T19N R1E	2,097–2,292	1.97
#1 Lamb	De Witt	Sec. 1 T20N R4E	1,632–1,790	0.73
#1 Rodman	De Witt	Sec. 12 T20N R4E	1,634–1,835	1.15
#4 Ryan	De Witt	Sec. 21 T21N R3E	1,562–1,762	1.32
#1 Schwartz	De Witt	Sec. 30 T21N R4E	1,753–1,948	1.71
#1 Durbin & Walsh	De Witt	Sec. 36 T21N R4E	1,631–1,829	2.36
#1 Christison	Logan	Sec. 1 T18N R1W	2,002–2,198	3.09
#1 Park	Logan	Sec. 7 T19N R3W	1,518–1,700	0.93
#1 Rocky Ford	Logan	Sec. 8 T19N R3W	1,612–1,746	2.85
#1 Lake	Logan	Sec. 11 T20N R2W	1,820–2,016	2.62
#1 Johnson "A"	Hancock	Sec. 6 T3N R5W	605–742	0.90
#1 Laffey	Hancock	Sec. 17 T3N R7W	690–730	0.67
#1 Evans	Hancock	Sec. 25 T4N R5W	515–663	0.95
#1 Rice	Hancock	Sec. 28 T4N R5W	573–690	0.47
#1 Tobias	Hancock	Sec. 24 T4N R7W	695–735	0.82
#1 Null	Mason	Sec. 19 T22N R6W	1,109–1,289	0.79
#1 Hahn	Mason	Sec. 31 T22N R8W	950–1,140	0.97
#1 Sparks	Mason	Sec. 31 T23N R6W	1,125–1,320	1.04
#1 Ewing	McDonough	Sec. 13 T4N R2W	750–930	1.63
#1 Chipman	McDonough	Sec. 23 T4N R2W	760–876	2.36
#1 Raymond	McDonough	Sec. 21 T4N R3W	585–770	1.53
#1 Hagon	McDonough	Sec. 2 T4N R4W	487–650	0.90
#1 Daniels	McDonough	Sec. 7 T4N R4W	435–548	1.40
#1 Mathews	McDonough	Sec. 20 T4N R4W	435–630	0.55
#1 Babcock	Edgar	Sec. 4 T12N R13W	2,352–2,606	0.99
#2 Stonebutner	Edgar	Sec. 3 T13N R13W	2,089–2,326	0.66
#1 Honnold	Edgar	Sec. 1 T13N R14W	1,927–2,165	1.43
#1 Woods	Edgar	Sec. 27 T15N R13W	1,785–1,892	5.52
#1 Hughes, Powers et al.	Edgar	Sec. 15 T15N R14W	1,327–?	2.27
#1 McReynolds	Moultrie	Sec. 18 T14N R4E	3,183–3,393	1.12
#1 Beachy	Moultrie	Sec. 13 T15N R6E	3,314–3,518	1.66
#1 Rumbold	Peoria	Sec. 5 T6N R6E	803–972	1.89
#1 Hanna City	Peoria	Sec. 10 T8N R6E	1,145–1,346	0.88
#6 Elmwood	Peoria	Sec. 7 T9N R5E	1,020–1,115	0.86
#2 Princeville	Peoria	Sec. 13 T11N R6E	1,005–1,195	0.66
#1 Connelly	Peoria	Sec. 3 T11N R8E	1,135–1,305	0.31
#1 King	Adams	Sec. 6 T2N R6W	727–785	0.44
#1 Lierly	Adams	Sec. 35 T1S R5W	733–829	0.52
#3 X Pierce	Adams	Sec. 36 T1S R5W	672–842	7.26
#1 Vollbracht	Adams	Sec. 12 T1S R6W	724–867	4.74
#1 Morris	Adams	Sec. 16 T1S R6W	576–735	1.72
#1 Wright	Adams	Sec. 2 T2S R5W	651–829	1.38
#1 Mowen	Adams	Sec. 4 T2S R5W	580–760	0.87
#1 Fornoff	Tazewell	Sec. 6 T23N R6W	1,015–1,202	1.81
#1 Howe	Tazewell	Sec. 14 T24N R2W	1,556–1,728	2.18

Appendix A *continued*

Well	County	Location	Depth (ft)	TOC (%)
#1 Proehl	Tazewell	Sec. 29 T24N R6W	878–1,066	1.51
#1 Zuercher	Tazewell	Sec. 29 T26N R3W	1,320–1,479	0.80
#1 Ackers	Schuyler	Sec. 9 T1N R1W	605–785	0.47
#1 Thompson	Schuyler	Sec. 25 T1N R2W	620–785	0.81
#1 Trone Estate	Schuyler	Sec. 10 T2N R1E	725–880	1.98
#1 Hare	Schuyler	Sec. 8 T2N R2W	657–851	1.40
#1 Hillyer	Schuyler	Sec. 7 T2N R3W	591–782	1.78
#1 Greuel	Schuyler	Sec. 7 T3N R1W	613–684	1.66
#1 Applegate	Schuyler	Sec. 9 T3N R2W	740–909	1.68
#1 DuBois	Schuyler	Sec. 2 T3N R4W	485–662	1.16
#1 Peacock	Schuyler	Sec. 11 T2N R4W	645–831	0.61
#1 Byland	Knox	Sec. 10 T10N R3E	775–967	1.03
#3 Galesburg City	Knox	Sec. 2 T11N R1E	622–800	0.54
#2 Knoxville Dity	Knox	Sec. 28 T11N R2E	705–885	0.68
#1 Schaefer	Wabash	Sec. 31 T2N R11W	4,690–5,026	2.82
#1 Volk	Brown	Sec. 3 T1N R3W	675–863	1.05
#1 McCleland	Brown	Sec. 11 T1N R3W	581–603	1.03
#1 Mohrman	Brown	Sec. 25 T1S R1W	562–700	0.44
#1 Giles Sailer	Brown	Sec. 1 T1S R3W	677–839	0.77
#1 Keltz	Brown	Sec. 3 T1S R3W	692–860	0.80
#1 Matlavish	Perry	Sec. 36 T4S R2W	3,800–3,984	1.34
#1 Schwartzkopf	Perry	Sec. 13 T4S R4W	3,492–3,661	1.17
#1 Miller	Vermillion	Sec. 2 T17N R13W	2,147–2,390	0.92
#1 Kelley	Vermillion	Sec. 1 T20N R11W	1,616–1,878	1.36
#1 Boyer	Monroe	Sec. 19 T1S R10W	650–790	0.38
#1 Krestner	Monroe	Sec. 20 T2S R9W	879–995	0.53
#1 Schuster	Monroe	Sec. 13 T3S R8W	1,595–1,738	0.80
Tolin	Monroe	Sec. 7 T3S R9W	700–820	1.15
#1 Dill	Monroe	Sec. 13 T3S R10W	800–904	1.02
#1 Aubuchon	Monroe	Sec. 1 T4S R9W	1,062–1,180	0.35
#1 Rayburn	Monroe	Sec. 12 T4S R10W	812–904	0.66
#1 Hodges	Alexander	Sec. 35 T15S R2W	660–840	0.93
#1 Minton	Alexander	Sec. 4 T15S R3W	120–270	0.29
#1 Neat	Scott	Sec. 17 T13N R12W	600–790	1.27
#1 Aydelott	Scott	Sec. 5 T13N R13W	394–580	1.27
#1 Mueller	Scott	Sec. 2 T15N R13W	720–900	0.58
#1 Tash	Scott	Sec. 24 T15N R14W	497–683	0.80
#1 Hoadley	Warren	Sec. 11 T9N R1W	540–735	0.81
#1 Monmouth City	Warren	Sec. 29 T11N R2W	600–755	1.06
#2 Village Alexis	Warren	Sec. 1 T12N R2W	534–720	0.50

APPENDIX B

Total organic carbon data of five shale samples from Maquoketa Group (Barrows 1985)

Sample	County	Location	Depth (ft)	TOC (%)
DWS-398	Hamilton	Sec. 6 T6S R7E	6,495	1.44
DWS-484	Perry	Sec. 28 T5S R3N	3,850	0.53
DWS-507	Clinton	Sec. 33 T3N R1W	3,770	1.30
DWS-563	Effingham	Sec. 15 T6N R6E	5,040	1.09
DWS-1016	Gallatin	Sec. 29 T9S R9E	6,310	1.02

APPENDIX C

Definitions for Rock-Eval measurements and results interpretation:

Rock-Eval Measurements

T_{max}	temperature maximum (°C), a thermal index, obtained from the Rock-Eval S_2 peak
S_1	amount of hydrocarbons (HC) obtained during low temperature pyrolysis, indicating the amount of HC trapped in the shale (mg HC/g rock or kg HC/ton rock)
S_2	amount of HC obtained during higher temperature pyrolysis, indicating the amount of HC capable of being produced with sufficient time and depth of burial (mg HC/g rock or kg HC/ton rock)
S_3	quantity of organic CO_2 obtained during pyrolysis (mg CO_2/g rock)

Interpretation of Results

Kerogen type

On the basis of the relative amounts of hydrogen and oxygen present in organic matter, kerogen can be classified using the modified van Krevelen diagram—a plot of hydrogen index (HI) relative to oxygen index (OI)—in Tissot and Welte (1984). The value of HI was calculated from the value $100(S_2)$/TOC and that of OI from $100(S_3)$/TOC.

Temperature maximum (T_{max})

Classification (French Petroleum Institute)

<435°C	Immature source rock
435 to 450°C	Mature source rock for oil
450 to 470°C	Mature source rock for gas

Generative potential (S_1+S_2)

The generative potential indicates the maximum amount of hydrocarbon capable of being produced (in kg of HC/ton of rock).

Classification (Tissot and Welte 1984)

<2 kg/t	Not an oil-source rock; some potential for gas
2 to 6 kg/t	Moderate source-rock potential
>6 kg/t	Good source-rock potential
100 or 200 kg/t	Excellent source-rock potential; oil shale

For parameters not discussed in this report, refer to the Rock-Eval analyzer (Delsi II) operation manual.

APPENDIX D

Sample identification, pyrolysis (Rock-Eval) data, and total organic carbon (TOC) data for the New Albany Group (Rock-Eval parameters defined in appendix C)

Sample	Geol. no.	Depth ft	Forma- tion*	Qty g	T_{max} °C	S_1	S_2	S_3	PI	S_2/S_3	PC	TOC	HI	OI	S_1+S_2
S00096	04IL01C1	323.3	HBSV	100.0	428	0.01	0.08	0.03	0.12	0.26	0.00	0.55	14	54	0.09
S00097	04IL02C1	333.05	HBSV	100.0	426	0.01	0.09	0.11	0.10	0.81	0.00	0.63	13	16	0.10
S00098	04IL03C1	343.4	HBSV	100.0	429	0.02	0.09	0.02	0.20	4.50	0.00	0.49	18	4	0.11
S00099	04IL04C1	353.05	HBSV	100.0	431	0.02	0.12	0.00	0.14		0.01	0.65	18	0	0.14
S00100	04IL05C1	363.3	HBSV	107.8	431	0.01	0.19	0.29	0.05	0.65	0.01	0.84	22	34	0.20
S00101	04IL06C1	373.15	HBSV	100.0	432	0.02	0.19	0.00	0.10		0.01	0.95	20	0	0.21
S00102	04IL07C1	383.45	HBSV	100.0	431	0.02	0.19	0.00	0.10		0.01	0.65	29	0	0.21
S00103	04IL08C1	393.1	HBSV	100.0	431	0.03	0.25	0.00	0.11		0.02	0.82	30	0	0.28
S00104	04IL09C1	403.5	HBSV	100.0	434	0.06	0.74	0.01	0.07	74.00	0.06	0.95	77	1	0.80
S00105	04IL10C1	413.45	HBSV	100.0	433	0.06	0.75	0.05	0.07	15.00	0.06	0.74	101	6	0.81
S00106	04IL11C1	424.4	HBSV	101.0	433	0.04	0.65	0.02	0.06	32.50	0.05	1.45	44	1	0.69
S00107	04IL12C1	433.3	HBSV	100.0	437	0.08	1.23	0.10	0.06	12.30	0.10	0.91	135	10	1.31
S00108	04IL13C1	443.2	HBSV	100.0	437	0.23	4.43	0.28	0.05	15.82	0.38	2.01	220	13	4.66
S00109	04IL14C1	454.05	HBSV	100.0	435	0.40	7.79	0.50	0.05	15.58	0.68	2.96	163	16	8.19
S00110	04IL15C1	463.2	GRCK	98.3	431	0.18	4.10	0.39	0.04	10.51	0.35	1.83	224	21	4.28
S00111	04IL16C1	473.1	GRCK	101.1	428	0.56	10.04	0.94	0.05	10.68	0.88	2.75	365	34	10.60
S00112	04IL17C1	482.35	GRCK	101.0	431	0.74	12.62	0.72	0.06	17.52	1.11	3.55	355	20	13.36
S00113	04IL18C1	493.2	GRCK	101.0	430	0.02	0.21	0.17	0.09	1.23	0.01	0.61	34	27	0.23
S00114	04IL19C1	503.25	SDCK	101.0	434	0.04	0.72	0.12	0.05	6.00	0.06	0.57	126	21	0.76
S00115	04IL20C1	513.35	SDCK	101.6	435	1.05	24.44	1.08	0.04	22.62	2.12	5.31	460	20	25.49
S00116	04IL21C1	523.2	SDCK	101.0	438	0.13	2.52	0.19	0.05	13.26	0.22	1.22	206	15	2.65
S00117	04IL22C1	533.0	SDCK	100.0	434	0.32	5.07	0.44	0.06	11.52	0.44	2.26	224	19	5.39
S00118	04IL23C1	542.2	SDCK	101.7	435	0.24	3.62	0.16	0.06	22.62	0.32	1.87	193	8	3.86
S00119	04IL24C1	553.4	SDCK	100.9	438	0.33	7.13	0.48	0.04	14.85	0.62	2.18	327	22	7.46
S00121	04IL26C1	573.0	SDCK	99.9	439	0.34	6.61	0.51	0.05	12.96	0.57	2.84	232	17	6.95
S00161	04IL27L1	582.6	SDCK	100.4	433	0.00	0.09	0.25	0.00	0.36	0.00	0.60	15	41	0.09
S00123	04IL28C1	593.2	SDCK	122.7	434	0.01	0.13	0.17	0.07	0.76	0.01	0.55	23	30	0.14
S00073	06ILO4C1	933.4	HBSV	100.9	432	0.00	0.08	0.31	0.00	0.25	0.00	0.57	14	54	0.08
S00074	06IL05C1	943.5	HBSV	103.3	431	0.00	0.14	0.21	0.00	0.66	0.01	0.32	43	65	0.14
S00076	06IL07C1	962.25	HBSV	103.0	432	0.01	0.13	0.13	0.07	1.00	0.01	0.49	26	26	0.14
S00077	06IL08C1	973.35	HBSV	102.1	432	0.00	0.15	0.07	0.00	2.14	0.01	1.09	13	6	0.15
S00078	06IL09C1	984.2	HBSV	100.4	429	0.01	0.10	0.09	0.10	1.11	0.00	0.22	45	40	0.11
S00079	06IL10C1	993.1	HBSV	100.0	435	0.07	0.49	0.17	0.12	2.88	0.04	0.73	67	23	0.56
S00080	06IL11C1	1003.2	HBSV	102.2	435	0.04	0.72	0.11	0.05	6.50	0.06	0.99	72	11	0.76
S00081	06IL12C1	1014.1	HBSV	99.7	435	0.07	1.12	0.16	0.06	7.00	0.09	0.97	115	16	1.19
S00082	06IL13C1	1024.1	HBSV	100.5	436	0.04	0.75	0.14	0.05	5.35	0.06	0.90	83	15	0.79
S00164	06IL13L1	1025.5	HBSV	103.4	439	0.06	1.11	0.07	0.05	15.85	0.09	1.34	82	5	1.17
S00165	06IL13L2	1029.1	HBSV	100.6	439	0.23	4.87	0.26	0.05	18.73	0.42	1.74	279	14	5.10

APPENDIX D *continued*

Sample	Geol. no.	Depth ft	Formation*	Qty g	T_{max} °C	S_1	S_2	S_3	PI	S_2/S_3	PC	TOC	HI	OI	S_1+S_2
S00166	06IL14L1	1032.75	HBSV	100.8	439	0.04	0.69	0.11	0.06	6.27	0.06	0.97	71	11	0.73
S00084	06IL15C1	1044.1	HBSV	100.1	437	0.12	2.17	0.18	0.05	12.05	0.19	1.45	149	12	2.29
S00085	06IL16C1	1053.15	HBSV	100.0	437	0.10	1.58	0.23	0.06	6.86	0.14	1.13	139	20	1.68
S00086	06IL17C1	1063.25	HBSV	101.4	436	0.33	5.59	0.45	0.06	12.42	0.49	2.46	227	18	5.92
S00087	06IL18C1	1073.3	HBSV	93.4	426	0.71	13.41	0.59	0.05	22.72	1.17	4.14	323	14	14.12
S00088	06IL19C1	1083.2	GRCK	94.7	426	1.34	25.68	1.18	0.05	21.76	2.25	6.11	420	19	27.02
S00167	06IL19L1	1085.25	GRCK	99.2	429	1.97	32.72	1.47	0.06	22.25	2.89	7.58	431	19	34.69
S00089	06IL2OC1	1093.35	GRCK	76.3	420	3.01	41.70	1.40	0.07	29.78	3.72	9.52	435	14	44.71
S00168	06IL21L1	1101.8	GRCK	98.2	434	1.61	25.88	0.83	0.06	31.18	2.29	4.89	529	16	27.49
S00090	06IL21C1	1103.1	GRCK	95.0	435	1.45	25.30	0.64	0.05	39.53	2.22	5.69	444	11	26.75
S00169	06IL22L1	1111.4	SDCK	94.6	438	0.83	17.59	0.55	0.05	31.98	1.53	3.06	574	17	18.42
S00091	06IL22C1	1113.4	SDCK	94.6	431	0.95	19.09	2.21	0.05	8.77	1.07	3.82	498	57	20.04
S00092	06IL23C1	1123.5	SDCK	87.9	436	0.64	12.90	0.64	0.05	20.15	1.12	3.63	355	17	13.54
S00093	06IL24C1	1133.5	SDCK	101.7	439	0.09	1.90	0.40	0.05	4.75	0.16	1.08	175	37	1.99
S00170	06IL25L1	1141.1	SDCK	102.4	438	0.10	2.06	0.37	0.05	5.50	0.18	0.94	219	39	2.16
S00094	06IL25C1	1143.5	SDCK	97.9	436	0.52	10.65	0.35	0.05	30.92	0.93	2.81	379	12	11.17
S00171	06IL25L2	1145.7	CDVL	103.5	411	0.28	4.28	0.52	0.05	8.23	0.37	1.52	281	34	4.56
S00051	02IL01C1	3011.4	HBSV	105.3	438	0.46	2.80	0.16	0.14	17.50	0.27	1.61	173	9	3.26
S00052	02IL02C1	3021.4	HBSV	99.6	437	1.52	5.74	0.42	0.21	13.66	0.60	2.37	242	17	7.26
S00053	02IL03C1	3043.3	GRCK	69.5	438	2.53	28.12	0.82	0.08	34.29	2.55	6.64	423	12	30.65
S00055	02IL04C2	3059.5	GRCK	57.7	438	2.65	30.38	0.81	0.08	37.50	2.75	8.45	359	9	33.05
S00056	02IL05C1	3065.3	GRCK	94.4	431	3.72	41.05	0.91	0.08	45.10	3.73	9.21	445	9	44.77
S00039	02IL05L2	3071.5	GRCK	102.3	436	2.15	12.57	0.56	0.14	22.44	1.22	2.54	494	22	14.72
S00057	02IL06C1	3072.4	GRCK	72.3	437	2.48	26.41	0.73	0.09	36.17	2.40	7.12	370	10	28.89
S00040	02IL06L2	3081.1	SDCK	101.1	440	2.25	10.34	0.56	0.18	18.46	1.05	2.60	397	21	12.59
S00058	02IL07C1	3085.5	SDCK	84.4	441	1.94	14.95	0.50	0.11	29.90	1.40	4.22	354	11	16.89
S00059	02IL08CL	3096.5	SDCK	68.4	439	1.72	20.93	0.73	0.08	28.67	1.88	6.17	339	11	22.65
S00352	01IN01C1	2504.2	GRCK	81.3	436	5.90	55.30	1.18	0.10	46.86	5.10	12.96	426	9	61.2
S00353	01IN01C2	2505.9	GRCK	89.3	439	4.59	41.16	0.81	0.10	50.81	3.81	9.38	438	8	45.75
S00354	01IN02C1	2515.7	GRCK	81.9	439	3.66	32.96	1.19	0.10	27.69	3.05	7.18	459	16	36.62
S00355	01IN03C1	2521.5	GRCK	85.6	437	3.27	20.50	1.77	0.10	16.10	2.64	6.78	420	26	23.77
S00356	01IN03C2	2524.2	GRCK	90.9	435	3.17	32.12	2.20	0.09	14.60	2.94	7.35	437	29	35.29
S00357	01IN03C3	2528.2	GRCK	83.3	436	3.75	41.63	3.21	0.08	12.96	3.78	9.94	418	32	45.38
S00358	01IN04C1	2531.4	GRCK	78.4	428	4.52	48.16	4.48	0.09	10.75	4.39	11.69	411	38	52.68
S00359	01IN04C2	2536.9	GRCK	81.0	433	4.53	40.49	4.93	0.10	8.21	3.75	9.46	428	52	45.02
S00360	01IN05C1	2545.1	GRCK	79.4	440	3.69	46.85	5.08	0.07	9.22	4.21	8.24	568	61	50.54
S00361	01IN05C2	2547.5	GRCK	84.5	440	3.34	35.36	4.68	0.09	7.55	3.22	6.58	537	71	38.70
S00362	01IN05C3	2549.9	GRCK	80.7	441	3.25	35.14	4.16	0.08	8.44	3.19	6.31	556	65	38.39
S00363	01IN07C1	2561.8	GRCK	89.0	437	1.92	11.70	3.10	0.14	3.77	1.13	2.93	399	105	13.62

Appendix D *continued*

Sample	Geol no.	Depth ft	Formation*	Qty g	T_{max} °C	S_1	S_2	S_3	PI	S_2/S_3	PC	TOC	HI	OI	S_1+S_2
S00364	01IN07C2	2565.6	GRCK	88.8	437	2.00	12.79	2.07	0.14	6.17	1.23	3.28	389	63	14.79
S00365	01IN08C1	2571.5	GRCK	88.7	436	2.71	23.40	2.05	0.10	11.41	2.17	5.18	451	39	26.11
S00366	01IN08C2	2579.0	GRCK	87.7	440	3.19	35.48	1.98	0.08	17.91	3.22	7.11	499	27	38.67
S00367	01IN09C1	2585.6	GRCK	89.2	436	3.76	43.54	2.66	.08	16.36	3.94	9.37	464	28	47.30
S00368	01IN09C2	2589.3	GRCK	101.0	441	1.07	7.98	2.53	0.12	3.15	0.75	2.01	397	125	9.05
S00369	01IN10C1	2590.7	SELM	108.9	436	0.14	0.62	2.24	0.18	0.27	0.06	0.50	124	448	0.76
S00370	01IN10C2	2591.5	SELM	101.1	439	1.71	15.74	1.81	0.10	8.69	1.45	3.41	461	53	17.45
S00371	01IN10C3	2598.8	SELM	99.0	436	2.71	34.30	1.93	0.07	17.77	3.08	6.77	506	28	37.01
S00372	01IN11C1	2600.5	SELM	97.1	436	3.55	44.73	2.40	0.07	18.63	4.02	8.88	503	27	48.28
S00373	01IN11C2	2606.3	SELM	97.1	438	2.14	20.43	3.00	0.09	6.81	1.88	4.82	423	62	22.57
S00374	01IN11C3	2619.2	BLCR	93.3	439	2.19	22.72	2.70	0.09	8.41	2.07	5.34	425	50	24.91
S00375	01IN13C1	2622.8	BLCR	86.2	437	2.64	25.84	3.20	0.09	8.07	2.37	6.30	410	50	28.48
S00376	01IN13C2	2626.5	BLCR	92.1	440	1.70	28.31	3.04	0.06	9.31	2.50	6.16	459	49	30.01
S00403	12IL01C2	4838	GRCK	87.0	443	2.42	19.95	0.52	0.11	38.36	1.86	5.74	347	9	22.37
S00405	12IL01C4	4846.25	GRCK	84.5	442	2.23	15.76	0.62	0.11	25.41	1.48	5.03	313	12	17.79
S00407	13IL04C1	5046.3	HBSV	100.0	433	0.19	0.26	1.06	0.43	0.24	0.03	0.96	27	110	0.45
S00408	13IL05C1	5054.6	GRCK	82.0	443	2.43	23.53	1.15	0.09	20.46	2.16	6.63	354	17	25.96
S00409	13IL06C2	5069.6	GRCK	82.3	440	2.61	15.40	1.03	0.14	14.95	1.50	5.31	290	19	18.01
S00410	13IL07C2	5078.1	GRCK	88.3	442	3.56	25.68	1.14	0.12	22.52	2.43	7.15	359	15	29.24
S00411	13IL08C1	5082.2	GRCK	82.1	439	3.17	22.19	1.16	0.12	19.12	2.11	7.04	315	16	25.36
S00412	13IL09C1	5090.3	GRCK	83.5	437	3.25	25.26	1.18	0.11	21.40	2.37	8.35	302	14	28.51
S00413	13IL10C1	5100.3	GRCK	82.0	437	3.28	25.70	1.23	0.11	20.89	2.41	8.67	296	14	28.98
S00414	13IL11C2	5115.4	GRCK	83.6	435	3.12	20.40	1.26	0.13	16.19	1.96	7.11	286	17	23.52
S00415	13IL12C3	5128.6	GRCK	84.0	437	2.80	18.16	1.16	0.13	15.65	1.74	6.20	292	18	20.96
S00416	13IL13C2	5135.3	GRCK	94.6	438	3.43	18.75	1.15	0.15	16.30	1.84	6.29	298	18	22.18
S00417	13IL14C3	5148.4	GRCK	82.1	439	2.9	27.33	1.20	0.10	22.77	2.52	7.72	354	15	30.32
S00418	13IL15C2	5154.3	GRCK	80.9	441	3.38	36.14	1.21	0.09	29.86	3.29	8.92	405	13	39.52
S00420	13IL17C4	5178.2	GRCK	86.7	440	2.01	11.25	1.13	0.15	9.95	1.10	4.35	258	25	13.26
S00421	13IL18C2	5184.1	GRCK	85.9	440	2.28	14.27	0.96	0.14	14.86	1.37	4.30	331	22	16.55
S00422	13IL19C1	5190.2	SELM	83.1	442	1.37	5.45	1.04	0.20	5.24	0.56	2.23	244	46	6.82
S00423	13IL20C1	5202.1	SELM	81.0	439	1.48	9.39	1.00	0.14	9.39	0.90	2.94	319	34	10.87
S00424	13IL21C2	5214.0	SELM	82.4	442	1.97	17.25	0.86	0.10	20.05	1.60	4.83	357	17	19.22
S00425	13IL22C2	5224.5	SELM	83.9	440	1.08	5.25	0.81	0.17	6.48	0.52	2.26	232	35	6.33
S00426	13IL23C4	5239.6	SELM	84.2	440	2.92	14.39	0.76	0.17	18.93	1.44	5.48	262	13	17.31
S00427	13IL24C2	5245.5	SELM	89.4	440	1.99	8.68	0.87	0.19	9.97	0.88	3.14	276	27	10.67
S00428	13IL25C3	5258.4	BLCR	88.5	444	1.43	11.57	0.91	0.11	12.71	1.08	4.00	289	22	13.0
S00429	13IL26C3	5267.2	BLCR	83.0	444	1.42	9.12	0.87	0.13	10.48	0.87	3.69	247	23	10.54
S00430	13IL27C1	5270.5	BLCR	84.2	443	1.29	7.96	0.89	0.14	8.94	0.77	3.47	229	25	9.25
S00043	03IL07L1	4480	GRCK	42.1	440	2.39	26.19	0.80	0.08	32.73	2.38	9.41	278	8	28.58

Appendix D *continued*

Sample	Geol no.	Depth ft	Formation*	Qty g	T_{max} °C	S_1	S_2	S_3	PI	S_2/S_3	PC	TOC	HI	OI	S_1+S_2
S00044	03IL12L1	4540	GRCK	12.1	411	3.71	26.94	1.15	0.12	23.42	2.55	8.52	316	13	30.65
S00045	03IL20L1	4590	SELM	99.1	445	0.63	3.78	0.28	0.14	13.50	0.36	1.64	230	17	4.41
S00046	03IL20L3	4673	SELM	100.4	443	1.14	8.97	0.43	0.11	20.86	0.84	3.51	255	12	10.11
S00047	03IL23L1	4676	BLCR	71.9	444	2.36	19.05	0.33	0.11	57.72	1.78	7.11	267	4	21.41
S00048	03IL26L1	4705	BLCR	98.0	445	3.11	24.08	0.28	0.11	86.00	2.26	7.87	305	3	27.19
S00002	01KY02C1	2191.15	GRCK	50.2	436	2.29	39.88	0.79	0.05	50.48	3.51	9.78	407	8	42.17
S00003	01KY)3C1	2220.30	GRCK	49.6	440	1.87	28.54	0.48	0.06	59.45	2.53	6.62	431	7	30.41
S00004	01KY04C1	2230.20	GRCK	99.4	444	0.42	4.34	0.20	0.09	21.70	0.39	1.64	264	12	4.76
S00005	01KY05C1	2240.10	GRCK	99.7	438	1.45	28.30	5.88	0.05	4.82	2.48	5.81	487	101	29.75
S00006	01KY06C1	2250.00	SELM	99.1	441	0.16	0.66	0.13	0.20	5.07	0.06	0.66	100	19	0.82
S00007	01KY07C1	2260.30	SELM	47.7	439	2.53	52.57	0.79	0.05	66.54	4.59	11.95	439	6	55.10
S00008	01KY08C1	2270.30	SELM	71.9	446	1.34	23.18	0.16	0.05	144.87	2.04	5.04	459	3	24.52
S00033	01KY08L1	2273.50	SELM	87.7	444	2.06	30.71	0.64	0.06	47.98	2.73	2.72	397	8	32.77
S00009	01KY09C1	2280.00	SELM	63.5	445	1.54	22.77	0.20	0.06	113.85	2.02	5.53	411	3	24.31
S00034	01KY10L1	2287.80	SELM	101.3	445	0.76	12.77	0.36	0.06	35.47	1.12	3.40	375	10	13.53
S00035	01KY11L1	2292.95	SELM	86.8	447	1.93	25.89	0.42	0.07	61.64	2.31	6.74	384	6	27.82
S00011	01KY11L1	2299.75	SELM	58.0	444	2.25	28.48	0.15	0.07	189.86	2.56	7.38	385	2	30.73
S00012	01KY12C1	2310.50	BLCR	88.4	441	1.66	19.34	0.15	0.08	128.93	1.75	5.67	341	2	21.00
S00036	01K712L1	2311.10	BLCR	87.3	446	1.54	19.40	0.41	0.07	47.31	1.74	5.70	340	7	20.94
S00037	01KY13L1	2312.65	BLCR	82.8	441	1.69	20.31	0.43	0.08	47.23	1.83	5.93	342	7	22.00
S00013	01KY13C1	2318.80	BLCR	71.7	444	1.93	26.06	0.23	0.07	113.30	2.33	7.71	338	2	27.99
S00330	11IL02C1	48.0	GRCK	98.0	444	0.69	3.50	0.39	0.17	8.97	0.34	5.77	60	6	4.19
S00331	11IL03C1	70.8	GRCK	94.1	452	0.55	2.66	1.42	0.17	1.87	0.26	4.41	60	32	3.21
S00377	11IL04L1	80.7	GRCK	100.8	451	0.37	2.54	1.94	0.13	1.30	0.24	4.37	58	44	2.91
S00378	11IL04L †	80.7	GRCK	100.9	434	0.09	0.77	3.34	0.10	0.23	0.07	1.91	40	174	0.86
S00332	11IL04C1	83.0	GRCK	98.4	457	0.78	4.23	2.00	0.16	2.11	0.41	5.86	72	34	5.01
S00333	11IL05C1	93.5	SELM	100.9	447	0.08	0.13	1.60	0.40	0.08	0.01	0.70	18	228	0.21
S00334	11IL06C1	101.45	SELM	99.1	446	0.24	0.58	1.72	0.29	0.33	0.06	1.23	47	139	0.82
S00337	11IL09C1	12.97	SELM	101.2	451	0.16	0.51	1.71	0.24	0.29	0.05	1.001	50	169	0.67
S00338	11IL10C1	141.35	SELM	101.2	452	0.20	0.60	1.45	0.25	0.41	0.06	1.28	46	113	0.80
S00379	11IL10L1	146.4	SELM	111.1	456	0.08	0.21	3.56	0.29	0.05	0.02	0.63	33	565	0.29
S00339	11IL11C1	152.0	SELM	100.9	446	0.25	0.65	1.00	0.28	0.65	0.07	1.30	50	76	0.90
S00380	11IL11L1	157.0	SELM	103.1	455	0.14	0.50	2.07	0.22	0.24	0.05	1.16	43	178	0.64
S00340	11IL12C1	164.0	SELM	99.2	450	0.53	1.99	0.80	0.21	2.48	0.21	3.26	61	24	2.52
S00341	11IL13C1	171.6	SELM	99.6	446	0.76	2.51	1.26	0.23	1.99	0.27	5.08	49	24	3.27
S00342	11IL14C1	184.85	SELM	102.5	451	0.41	1.84	1.82	0.18	1.01	0.18	2.84	64	64	2.25
S00343	11IL15C1	195.6	SELM	99.1	452	0.85	4.31	2.19	0.16	1.96	0.43	6.50	66	33	5.16
S00344	11IL16C1	205.1	SELM	100.0	456	0.62	2.10	2.42	0.23	0.86	0.22	3.50	60	69	2.72
S00345	11IL17C1	216.0	SELM	106.2	459	0.32	1.25	2.18	0.21	0.57	0.13	2.65	47	82	1.57

Appendix D *continued*

Sample	Geol no.	Depth ft	Formation*	Qty g	T_{max} °C	S_1	S_2	S_3	PI	S_2/S_3	PC	TOC	HI	OI	S_1+S_2
S00347	11IL18C1	230.0	SELM	100.3	456	0.27	0.93	1.62	0.22	0.57	0.10	1.81	51	89	1.20
S00348	11IL19C1	241.4	SELM	97.7	461	0.33	1.35	1.22	0.20	1.10	0.14	2.89	46	42	1.68
S00349	11IL20C1	251.4	SELM	99.6	460	0.29	1.32	1.00	0.18	1.32	0.13	3.41	38	29	1.61
S00350	11IL21C1	260.1	SELM	104.8	458	0.22	0.90	1.72	0.20	0.52	0.09	0.43	209	400	1.12

* Formation: HBSV, Hannibal and Saverton; GRCK, Grassy Creek; SDCK, Sweetland Creek; SELM, Selmier; BLCR, Blocher; and CDVL, Cedar Valley Limestone.
† Sample 11IL04L is a dike in 11IL04L1.

APPENDIX E

Ratios of pr/ph, pr/n-C_{17}, and ph/n-C_{18} for crude oils

Sample	pr/ph	pr/n-C_{17}	pr/n-C_{18}
Pennsylvanian			
57-Penn-1	2.0	0.6	0.4
55-Penn-3	2.0	0.9	0.5
36-Penn-1	1.9	0.6	0.4
50-Penn-1	2.0	0.6	0.4
49-Penn-1	2.0	0.7	0.6
Mississippian-Chesterian			
43-Ben-1	2.0	0.6	0.4
50-C-1	1.9	0.6	0.4
ISGS-150	1.9	0.9	0.5
025-C-1	1.8	0.5	0.3
20-Walt-1	1.7	0.9	0.6
025-C-2	1.8	0.6	0.4
ISGS-145	1.7	0.9	0.6
32-Ben-1	1.8	0.6	0.4
41-Ben-1	1.8	0.6	0.4
22-C-1	1.9	0.7	0.4
ISGS-139	1.8	0.8	0.5
20-Walt-2	2.0	0.7	0.4
53-C-1	2.0	0.6	0.4
ISGS-140	1.8	0.8	0.5
60-Beth-1	2.0	0.6	0.4
25-C-1	2.1	0.7	0.4
Mississippian-Valmeyeran			
96-Son-1	1.9	0.8	0.5
41-SG-1	1.8	0.5	0.3
73-Carp-1	2.0	0.8	0.4
ISGS-127	1.7	0.7	0.5
ISGS-143	1.7	0.7	0.5
22-AV-1	1.8	0.8	0.5
ISGS-144	1.7	0.7	0.5
35-AV-1	1.8	0.8	0.5
18-SG-1	1.8	0.5	0.3
ISGS-151	1.9	0.6	0.4
ISGS-129	1.7	0.9	0.5
40-SG-1	2.0	0.5	0.3
ISGS-128	1.7	1	0.7
53-SG-1	2.0	0.7	0.4
ISGS-137	1.7	0.8	0.5
ISGS-136	1.9	0.8	0.5
ISGS-135	1.6	0.8	0.5
ISGS-126	1.7	0.9	0.5
ISGS-134	1.7	0.8	0.5
ISGS-132	1.7	0.7	0.5
54-SG-1	2.0	0.5	0.3
ISGS-133	1.7	0.6	0.4
72-SG-1	2.0	0.8	0.5
ISGS-131	1.7	0.7	0.5
58-STL-1	1.8	0.6	0.4
039-Son-1	2.0	0.8	0.5

Sample	pr/ph	pr/n-C_{17}	pr/n-C_{18}
Devonian			
44-Dev-1	1.8	0.4	0.3
L-Dev	1.9	0.4	0.5
79-Dev-1	1.9	0.8	0.5
021-D-1	1.8	0.9	0.6
32-Dev-2	2.0	0.5	0.4
33-Dev-2	1.8	0.4	0.3
147-D-1	1.5	1.2	0.8
147-D-2	1.8	1.4	0.8
Silurian			
80-Sil-1	1.8	0.6	0.4
26-Sil-2	1.8	0.7	0.5
88-Sil-1	2.1	0.9	0.5
BAO-2	1.8	0.5	0.4
BAO-1	1.8	0.5	0.3
80-Sil-3	1.9	0.7	0.5
J-Sil-1	1.9	0.6	0.5
98-Sil-1	1.5	0.9	0.8
49-Sil-4	1.7	0.7	0.4
79-Sil-1	1.9	0.9	0.5
BAO-3	1.7	0.5	0.4
F-Sil-1	1.1	0.4	0.5
44-Sil-1	1.9	0.6	0.4
96-Sil-1	1.9	1.3	0.7
039-S-1	1.9	1.2	0.6
87-Sil-2	1.4	0.3	0.3
87-Sil-1	1.3	0.3	0.4
Ordovician (Trenton/Galena)			
46-T-1	1.5	0.2	0.3
43-T-2	1.5	0.2	0.2
25-T-1	1.2	0.2	0.3
33-T-2	1.5	0.2	0.2
33-T-1	1.7	0.2	0.2
45-T-1	1.7	0.3	0.3
90-T-1	1.5	0.4	0.3
73-T-1	1.5	0.3	0.2
32-T-1	1.4	0.2	0.3
45-T-2	1.4	0.2	0.3
50-T-1	1.5	0.2	0.3